Appendix D

Anomaly, Failure and Mishap Reporting

D.1 Introduction

In accordance with NSTS/ISS 13830, Payload Safety Review and Data Submittal Requirements, the AMS-02 Project has prepared this summary of anomalies, failures and Mishaps associated with flight and qualification hardware. This summary does not consider what are considered normal manufacturing deviations and discrepancies as failures or anomalies unless they rise to a clear safety impact status. All such manufacturing discrepancies associated with the AMS-02 Integration Hardware built and procured through Johnson Space Center are documented in the JSC QARC system.

Similar discrepancies from international suppliers of hardware are reported along with anomalies and failures to the AMS-02 Project Office, but only the anomalies and failures are recorded.

D.2 Significant Events

No.	ID	Title	Status
1.	**AMS-02-A01**	**HV Board Interconnect Failure.**	**Closed**
2.	**AMS-02-A02**	**Uninterruptible Power Supply FET Cracked**	**Closed**
3.	**AMS-02-A03**	**Improper Torquing of ECAL Fasteners**	**Closed**
4.	**AMS-02-A04**	**Anomaly of Thermal Conductor of AMS Internal Tracker**	**Closed**
5.	**AMS-02-A05**	**Cryomagnet Arcing Discharge During Initial Ground Testing**	**Closed**
6.	**AMS-02-A06**	**Magnet did not reach design maximum field during qualification testing**	**Closed**
7.	**AMS-02-A07**	**STE wiring disconnected during magnet qualification test**	**Closed**
8.	**AMS-02-A08**	**Failure Anomaly Report for DALLAS Temperature Sensors (DTS) in TRD-GAS Box-C Canister**	**Closed**
9.	**AMS-02-A09**	**Cryomagnet/Vacuum Case Burst Disk Post Vibration Test Anomaly**	**Closed**
10.	**AMS-02-A10**	**AMS-02 Super Fluid Helium Tank BD03 Duct Excessive Thermal Conductance**	**Closed**
11.	**AMS-02-A11**	**Battery Box Fire**	**Closed**
12.	**AMS-02-A12**	**Battery Cell Under Voltage**	**Closed**
13.	**AMS-02-A13**	**Excessive Helium Consumption in Pilot Valves to Cold Weka Valves**	
14.	**AMS-02-A14**	**Unreliable Cryosystem Pressure Sensors**	**Closed**
15.	**AMS-02-A15**	**DDRS-02 Error during EMI Testing**	**Closed**
16.	**AMS-02-A16**	**Leakage of Explosively Bonded Bimetallic Joint in Cryosystem**	**Closed**
17.	**AMS-02-A17**	**Warm Helium Gas Supply Regulator Divergence**	**Closed**
18.	**AMS-02-A18**	**Bubbles in Radiator Heaters**	
19	**AMS-02-A19**	**Cleanliness of inside of the Superfluid Helium Tank**	**Closed**
20.	**AMS-02-A20**	**Deviation from documented procedure for Installation of MLI Pins**	**Closed**

1. AMS-02-A01 – HV Board Interconnect Failure.

Description of Event: During thermal cycle testing high voltage electronics associated with the ECAL, RICH and TOF High Voltage power supplies experienced channel failures. Subsequent investigation indicated that during thermal cycling testing the straight forked pins that inteconnect the 16 mini-boards of the linear regulator were shown to have experienced thermally induced stresses that broke the solder connection. These thermal stresses were induced between the solder joint and the resin of the boards.

Corrective Action: The straight forked pins interconnecting between the 16 mini-boards were replaced in a test configuration and qualification unit 2 with reshaped pins that provide a strain relief function that the straight pins could not provide. A test board has been constructed and tested at CAEN as follows: 1) burn-in for 8 hours with a temperature of 70ºC ; 2) thermo-vacuum test with pressure of 0.1mBar, verifying the absence of discharges ; 3) thermal cycles (10 cycles in total between -30 ºC and +70 ºC, with a ramp-up rate of 4 ºC /min, down-ramp rate of 2 ºC /min and time of permanence at each temperature of 1 hour). At the end of each cycle, all the channels were inspected. No problem was observed.

Safety Impact: The loss of the high voltage sources within the RICH, ECAL and TOF would have had a significant impact on the science objectives of the AMS-02, but no significant impact to safety. Flight bricks will be fully potted, and the separation of the of the solder joint would not have created a sparking/ignition source concern or coronal discharge source. At worst this failure may have manifested as an increase in EMI noise because of intermittent contact and operation. This failure/anomaly has been classified as NON SAFETY CRITICAL.

Status: Closed

SUPPORTING DOCUMENTATION: (follows)

AMS-note 2005-09-02

Modifications of ECAL, RICH and TOF High Voltage Power Supply QM design

Marco Incagli – INFN Pisa

5 september 2005

This note describes the modifications applied to the QM2 version of the High Voltage Power Supply (*brick*), to be used by ECAL, RICH and TOF subdetectors. The modifications became necessaries in front of failures registered during thermal tests performed both by the supplying company (CAEN - Italy) and by the INFN-Pisa, responsible of the ECAL subdetector construction.

In this note we report (1) how the QM1 was constructed, (2) the failures observed, (3) the new design of the QM2 and the status of the tests necessary to validate the new design.

1 – Construction of QM1

The *AMS brick* is described in AMS note 2005-09-01 .

In short, it is a modular structure providing the High Voltage (from 0.5kV up to 2.5kV) for the readout Photomultipliers (PMTs) used by the three subdetectors.

Three main components characterize the brick:

1. *Controller Board* communicating with the AMS electronics through the LeCroy slow control protocol and providing the low voltages to the DC/DC converters ;
2. *DC/DC Converter* generating the HV (up to 2.5 kV) from the 28V supplied by the International Space Station ;
3. *Linear Regulators* regulating the output voltage to the PMTs with a precision of $\Delta V/1024$, where ΔV is the operative range of the readout .

The number of DC/DC convertors and Linear Regulators is different for the three subdetectors, as reported in AMS note 2005-09-01 .

The *Linear Regulator* consists of a main board, with approximate dimensions 5×20 cm^2, on which 16 *mini boards*, actually performing the HV regulation for each channel, are soldered in the vertical position (see picture 1). The soldering is done through *fork pins* which are shown in figure 2.

In the QM1, the *fork pins* had a straight shape, so that no strain relief was foreseen.

After soldering the 16 mini boards, all the Linear Regulator is filled with resin, both to limit discharges and to mechanically protect the electrical components.

2 – Tests done on QM1

The different parts of two *brick* for ECAL and TOF subdetectors were mounted, and tested at CAEN and at INFN Pisa (ECAL *brick,* only). After thermal cycles between -20^{o}C and +70^{o}C (and after some trips from Pisa to CERN!) the two HV modules showed some malfunctioning channels.

To investigate the problem, the TOF *brick* was dismounted and the Linear Regulators were carefully inspected. As a result, some of the SMD soldering of the straight pins were found to be broken, as shown in figure 3. According to CAEN, the failures were due to different thermal coefficient between resin and soldering material, generating a stress able to cause the connection rupture.

To solve the problem, CAEN suggested to modify the pin shape.

3 – Modifications on the design and tests on QM2

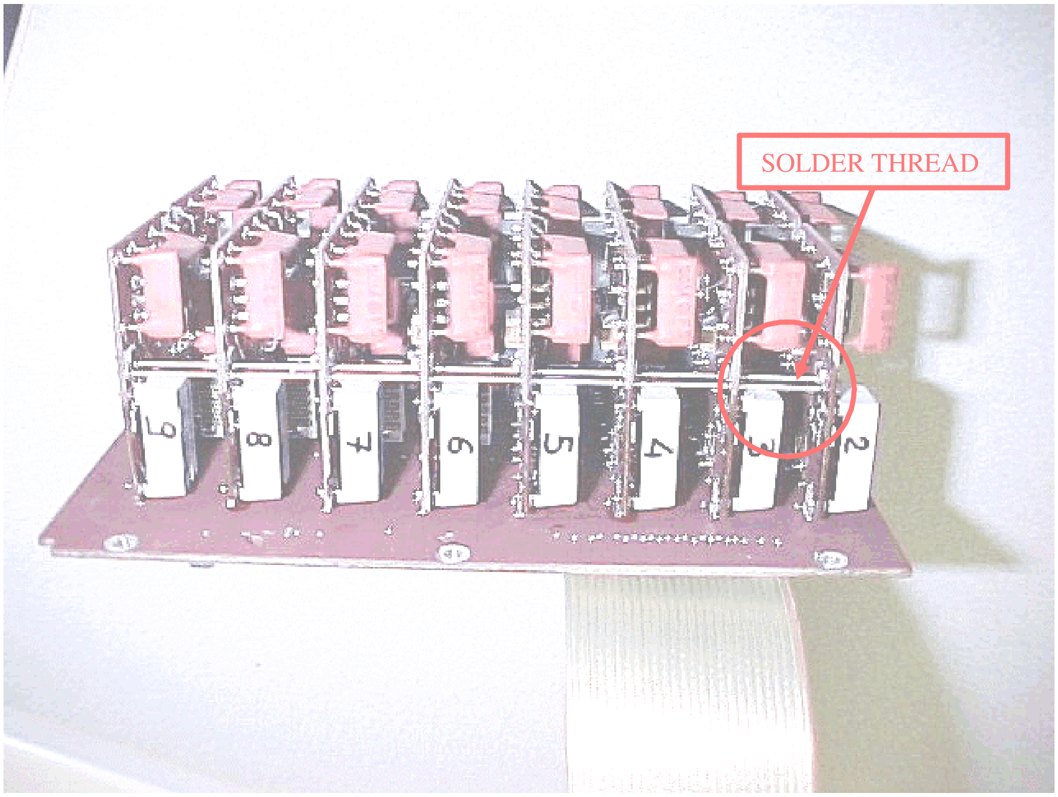
The CAEN proposal for the new pin shape is shown in figures 4 and 5. With this new shape, the pins should act as a strain relief and decrease the stress generated on the soldering pads by the thermal expansion.

A test board has been constructed and tested at CAEN as follows:

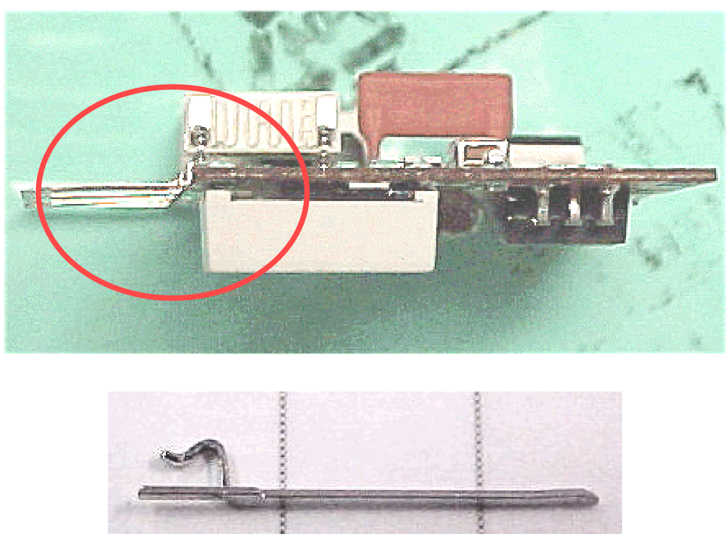
1. burn-in for 8 hours with a temperature of 70^{o}C ;
2. thermo-vacuum test with pressure of 0.1mBar, verifying the absence of discharges ;
3. thermal cycles (10 cycles in total between -30^{o}C and +70^{o}C, with a ramp-up rate of 4^{o}C/min, down-ramp rate of 2^{o}C/min and time of permanence at each temperature of 1 hour).

At the end of each cycle, all the channels were inspected. No problem was observed.

After these tests, a QM2 *brick* module, with 5 *Linear Regulator* boards and 1 *DC/DC converter*, was built to be tested by the RICH and ECAL groups. The tests will be performed in September 2005. Results will be reported in a following note.



Picture 1 – side view of TOF Linear Regulator.



Picture 2 – View of the single regulator mini board with closeup of the straight pins used used for the soldering of this component with the Linear Regulator main board.

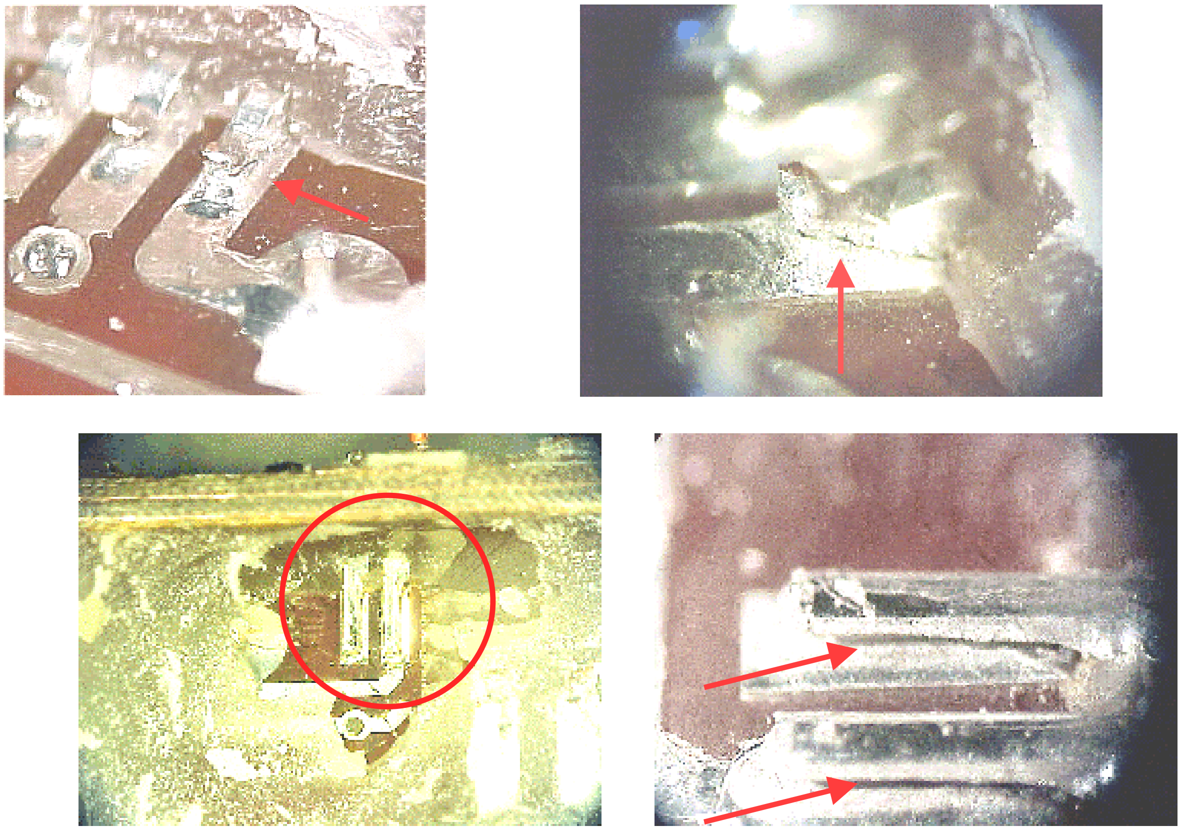


Figure 3 – Pictures of the pads where the *fork pins* were soldered.

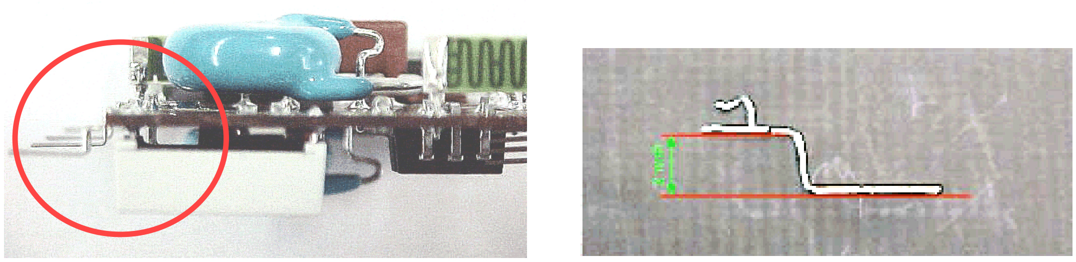


Figure 11 – New mini board with preformed pins(left). New shape of *fork pins* (right).

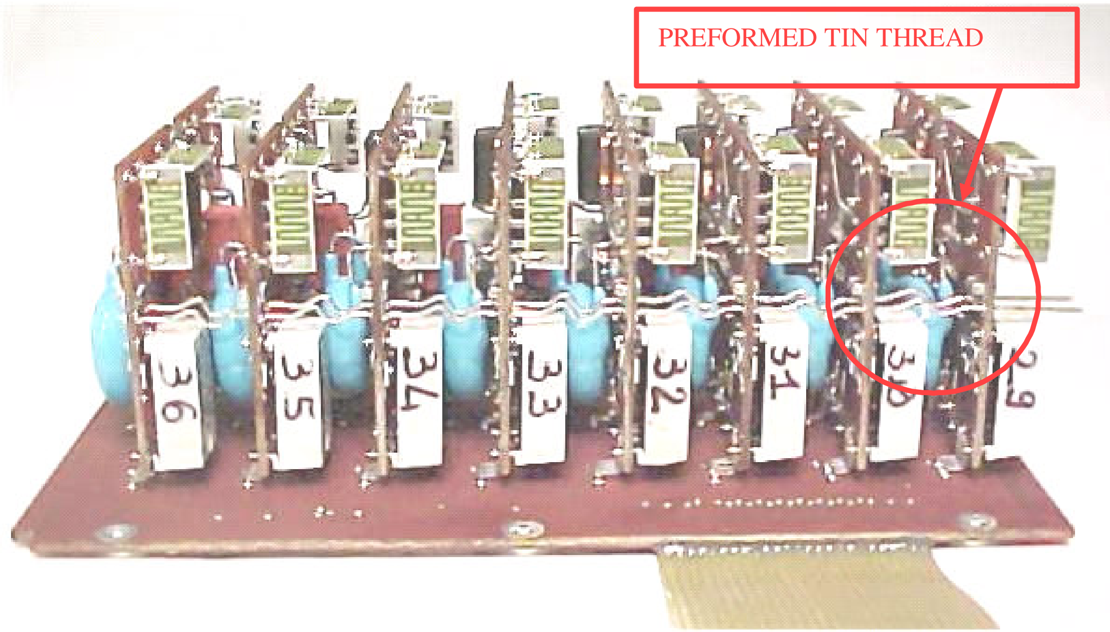


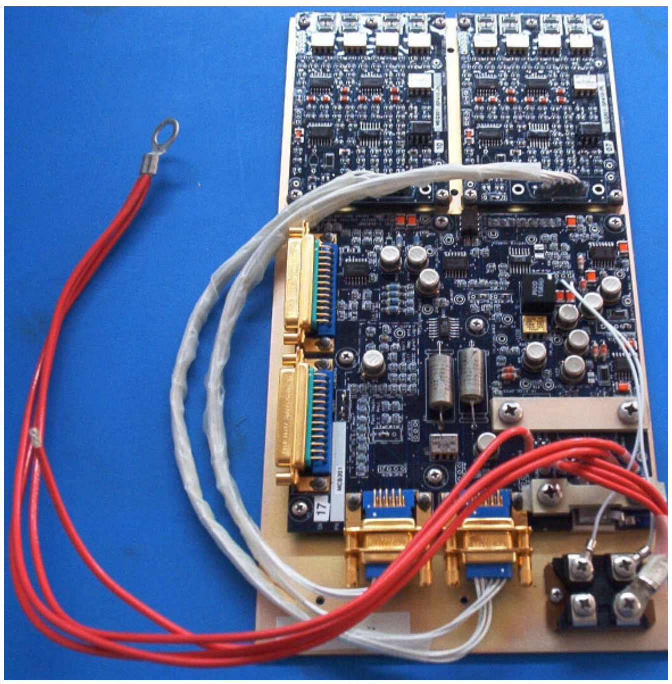
Figure 5 – QM2 test board. Also the interconnection thread has been preformed.

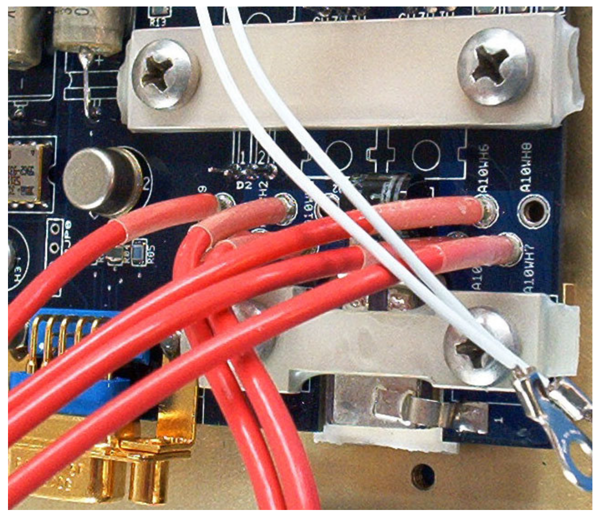
2. AMS-02-A02 – Uninterruptible Power Supply FET Cracked

Description of Event: During the final system testing of the full electronics assembly at Eaves Devices, the last board (5th out of 5) tested failed the current interruption test (support 77A for 360ms to 1500ms). Upon examination of the board, it was discovered that the FET was cracked under the compression bar holding it in contact with the heat sink. These cracks apparently shorted the device, causing it to fail under high current. As shown in the attached pictures, the FET (located in the front right of the AMS BMS picture, near all the big red wires) has a compression bar over the top of it, holding it in contact with two layers of SIL-PAD and an aluminum heat sink. Per Eaves Devices assembly procedures, the screws on this compression bar are only torqued to 6 in-lbs.

Further examination of the other 4 boards revealed that the FETs in those boards showed signs of cracking, but had not failed any testing.

The FET on the failed board was removed and an industrial version of the FET was put in place to test the rest of the circuitry and confirm that no other damage had been done. All circuits performed normally.





Corrective Action: Compression bar was eliminated from the design an a thermally conductive adhesive was used. Material usage was approved by JSC Materials. Thermal performance and board function were retested and found acceptable.

Safety Impact: The FET was functioning in a critical battery protection function, protecting the system against external shorts. Corrective actions were essential in maintaining system safety.

Status: Closed

3. AMS-02-A03 – Improper Torquing of ECAL Fasteners

Description of Event: The torques specified and used in the assembly of the ECAL were for a dry installed fastener interface. Dry install torques are higher than lubricated install torques due to the need to overcome the higher coefficient of friction of bare metal to metal contact. All of the structural inserts and nuts used to assembly the ECAL have a dry film lubricant coating that acts to reduce the friction of the fasteners during installation. Margins of safety for the ECAL fasteners were recalculated using the torques called out in the assembly process with a lubricated interface. The analysis results showed that possible yielding had occurred during the installation of the fasteners.

Corrective Action: All of the structural fasteners that showed negative margins of safety have been either be removed, inspected and reinstalled or be replaced with new fastener and preloaded to torques specified according the latest analysis results. Drawings/installation instructions indicating the dry insertion torques have been corrected to reflect correct lubricated values. Structural margins have been confirmed to be positive after rework.

Safety Impact: The ECAL bolts improperly installed failed to have sufficient structural margin, making this assembly error SAFETY CRITICAL. Corrective actions were witnessed to confirm full compliance and to assure positive margins were regained.

Status: Closed

4. AMS-02-A04 – Anomaly of Thermal Conductor of AMS Internal Tracker

Description of Event: During assembly copper braids used as thermal conductors were observed as having broken wire elements after undergoing in situ compression (a required process). None were found to be loose, but separated.

Corrective Action: Heat shrink tubing implemented over braids to contain any possible fragments. Fragment generation unlikely as copper conductors were only broken on one side and still retained on the other. Additional containment within tracker is provided by mesh filters at light tight vents.

Safety Impact: There was a potential of generating small debris that was electrically conductive. While this is not a concern beyond mission success for the Tracker, the loose wire fragments co-orbiting with the ISS was undesirable. The safety assessment considered this Safety Critical, and design features in place and corrective procedures were deemed adequate to protect against this remote hazard.

Status: Closed

SUPPORTING DOCUMENTATION: (follows)

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Report on Anomalies and Modifications of Thermal Connectors during Assembly of AMS Internal Tracker

Prof. Divic RAPIN

Date: September 1, 2006

Re: Thermal connectors (Copper braids) connecting to each other the thermal bars of planes 2, 3 and 4 of the tracker.

Location: University of Geneva clean rooms (veranda).

Observations: Some threads of the Copper braids used as thermal connectors between inner planes were found to be damaged during the assembly *(See Appendix A)*. The damaged threads are broken on one side only and none was found to be loose. The loss of thermal conductivity is negligible.

Reporting: AMS TIM July 2006 at CERN

Actions taken: Study of a containment procedure of the Copper braids using space qualified heat shrink tubing *(See Appendix B)*. This tubing must be installed *in situ* after vacuum cleaning of the braids with examination of the filter. The heating should not damage the electronics.

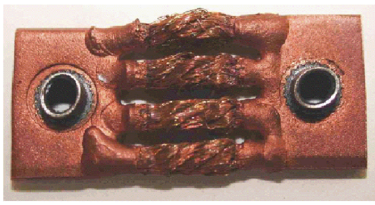
Results: Application of this procedure to the 192 thermal connectors of the inner tracker during its assembly. *(See Appendix C)*

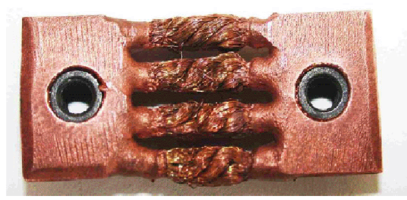
Safety assessment:

- No damaged thread was found to be loose.
- Damaged threads are broken on a single location, reducing the stress.
- Two containment barriers exist:
    1: heat shrink tubing around the braids (new).
    2: mesh in the light tight venting apertures containing material in the inner tracker.

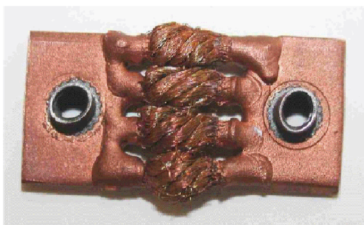
Appendix A: **Thermal connector compression, damages**

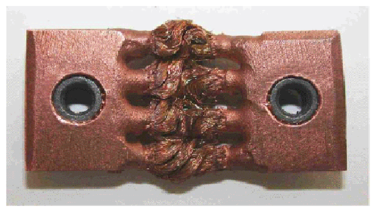
Thermal bars are connected by thermal connectors made of Copper braids welded to small plates. Both faces of one connector are shown below:





Compression along Z-axis is applied to the braids in order to restore flexibility and to adjust the length in Z. Pictures below show a connector after compression.





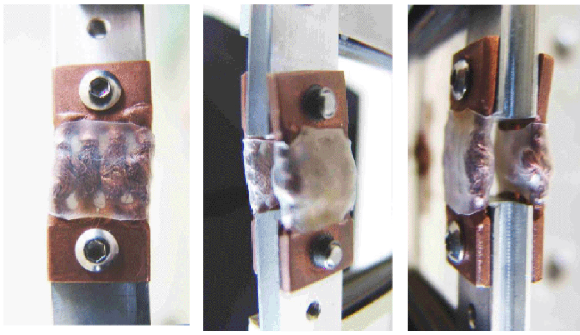
This compression was performed *in situ* during assembly of the 3 planes of the inner tracker but before the definitive connexion. Some braids were damaged:

Remarks:

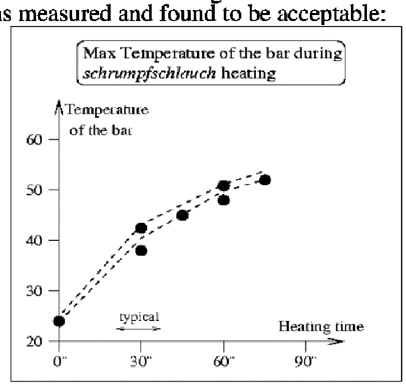
- Some weakness of the metal properties might have been introduced by the welding of the Copper braids
- The effect on thermal conductivity is negligible.
- The damaged threads showed a single break.
- No one was found to be loose.

Appendix B: **Containment of Copper braids**

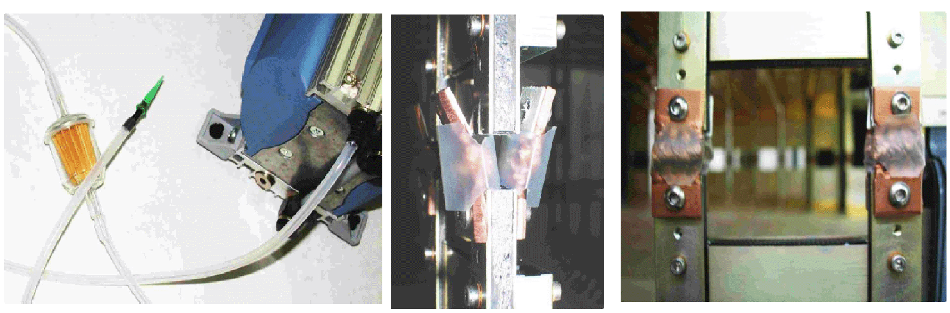
We studied the use of Kynar heat shrink tubing (space qualified) to enclose the Copper braids. Preliminary tests on prototypes are shown below:



The tube is heated during ~ 30 seconds. The effect on the temperature of electronic hybrid circuits was measured and found to be acceptable:



A procedure was established and was applied on all thermal connectors. A preliminary cleaning was made with a micro vacuum cleaner. The filter was examined. No broken thread was found in the filter.



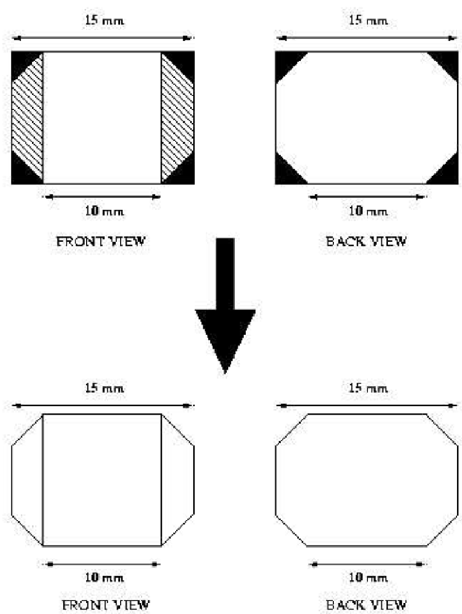
Appendix C: **Detailed implementation of procedure and controls**

AMS-02 Tracker : Heat-Shrink Tube Installation

Date : .... / .... / 200...	Time :	Done by : ....
Octant :	Column :	

1- Preparation of the Samples

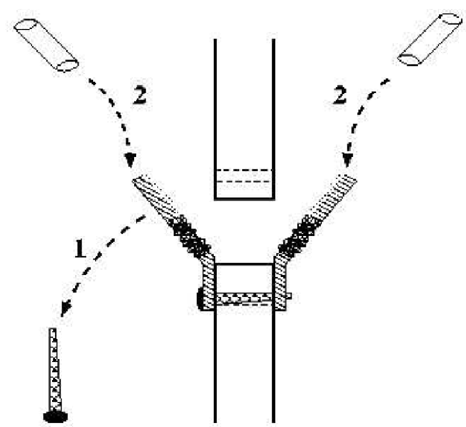
		Ok	Comment
1.	Take the Heat-Shrink Tube : diameter=21,1 mm (flattened).	☐	....
2.	Cut 4 Samples of 15 mm length.	☐	....
3.	Adjust the shape of the samples in accordance with the following pattern :	☐	....



4.	Clean the samples (Isopropyl alcohol).	☐	....

2- Installation

		Ok	Comment
1.	Protect the corresponding plane with a 'PlexiBulle' cover.	☐	....
2.	Find the location of the 4 copper connectors on the half-column.	☐	....
3.	Rectify copper braids which exceed the width of the copper connectors.	☐	....
4.	Unscrew the two pairs of copper connectors on the not-stuck side of the column.	☐	....
5.	Clean the braids with the vacuum pump equiped with a filter.	☐	....
6.	Check the filter.	☐	....
7.	Put the heat-shrink tubes on each pairs (adjust the form if necessary).	☐	....



		Ok	Comment
8.	Screw up the two pairs of connectors in order to maintain the tubes in the good position.	☐	....
9.	Use the 'micro-heater' (settings : 'heat'=3, 'blow'=5) to heat the heat-shrinkable tubes. Pay attention to the hot air direction (no hot air near the electronics boxes!)	☐	....
10.	Check that the heat-shrinkable tubes cover well the braided part of the copper connectors.	☐	....

5. AMS-02-A05 – Cryomagnet Arcing Discharge During Initial Ground Testing

Description of Event: During initial charging during pre-integration testing in a ground dewar assembly, the flight Cryomagnet experienced an electrical discharge exterior to its inductive coils that damaged circuit boards and structural cables. The cause of this event was an incomplete evacuation of the helium that the coils had been immersed in as part of the cool down procedure (not done in the flight configuration). The easily ionized residual helium allowed a corona discharge to form and carry the stored power of the superconducting magnet from the initiation point on a sensing circuit board to the grounding structure.

Corrective Action: 1) Ground dewar for containing the AMS-02 Cryomagnet was repaired to eliminate vacuum leaks that precluded total evacuation of helium gas.

2) Cryomagnet was carefully inspected to establish complete damage assessment of structural cables.

3) Damaged cables were carefully examined to establish the remaining number of strands at each damage location. Cables were "locked" with wedges and adhesive to preclude any single section of cable structural integrity loss would be isolated. Testing confirmed adequacy of design. Worst location received additional load sharing with plates and rods to offset loads.

4) Damaged cable sections were saturated with epoxy and wrapped with glass take to strengthen interstrand strength and preclude any "unwravelling."

5) Damaged Circuit boards were replaced.

6) Cryomagnet was energized and found to successful withstand magnetic field loading (the worst case structural loading on the damaged cables.)

Safety Impact: The damage to the structural cables that keep the magnetic coils structurally sound during the loading of the Cryomagnet's magnetic field is a significant safety concern. Analyses and the testing program for the corrective action showed that there was no significant reduction in load carrying capabilities and pose no threat to either the Shuttle or the ISS.

Status: Closed

SUPPORTING DOCUMENTATION: (follows)

6. AMS-02-A06 – Magnet did not reach design maximum field during qualification testing

Description of Event: During the magnet qualification testing, the team was unable to reach to full design current due to differences between the test configuration and the flight configuration. The magnet will never be run at a current higher than was tested on the ground. The magnet qualification testing included several current ramp-ups. During these tests, it is expected that the superconducting magnets will experience training quenches. The maximum design current is 459 Amps. While performing tests to reach this design current level, the magnet quenched at 411 Amps. During the next test, the magnet quenched at 408 Amps. Although it was originally believed that these quenches were training quenches, it was later determined that these quenches were caused by a thermal effect to do with the interaction of the persistent switch with the helium-filled cooling loop. This interaction is ramp-rate dependent, which means that it would probably be possible to reach higher currents in the magnet by charging more slowly. In principle, given enough time and schedule, the magnet could have been tested to a higher level. However given time and budget constraints, a decision was made to perform the final test to only 390 Amps in the Magnet Assembly Test Rig. A test to a higher value is still possible in the flight configuration, but a decision has not been made yet as to whether or not this additional testing will be performed. Trying to reach higher field in the flight cryostat carries a risk of bursting a burst disc, so the number of quenches should be minimized if possible.

Corrective Action: Utilize the magnet with a new current limit of only 424 Amps. This is acceptable for science, and minimizes the risk to damaging the flight system. A simple change of the ramp rate in the flight system, along with some minor movements of the cooling loop versus the current leads will minimize the risk of these same kind of thermal effect quenches occurring on the flight magnet. Additional tests will be performed on the flight magnet to ensure that it reaches the new full field without quenches.

Safety Impact: None. The magnet will be run at a field below the level that we have analyzed for safety. Structural qualifications, which originally were to use a magnetic field induced load to test the structure to demonstrate margin has been shown to be good by analysis to a FOS of 2.0. This analytic approach has been coordinated and approved by the SWG.

Status: Closed

SUPPORTING DOCUMENTATION: (none)

7. AMS-02-A07 – STE wiring disconnected during magnet qualification test

Description of Event: Prior to completing the assembly of the AMS Superconducting magnet, the magnet assembly was tested in a Magnet Assembly Test Rig. During this testing, several Special Test Equipment heaters were added to the magnet. These heaters were used to intentionally induce a quench in the magnet coils. Essentially, they were put in place to mimic the flight quench protection heaters or a random quench. The wiring for these heaters, which was also STE, was not adequately held in place to prevent movement during a quench. Essentially, the wires were bundled together with Kapton tape only (Figures 1 and 2). At the operating temperature of 1.8 Kelvin, the adhesive on the Kapton tape was not adequate to hold the wires together. During a magnet quench several of the wires experienced loads induced by the rapidly changing magnetic fields. These loads moved and pulled some of these wires out of the STE circuit board or the heater (Figure 3). The result of this was that several of the test necessary heaters to ensure no damage is done to the magnet were not functioning and the test had to be abandoned.

Figure 1: Test Wiring Before Magnet Testing

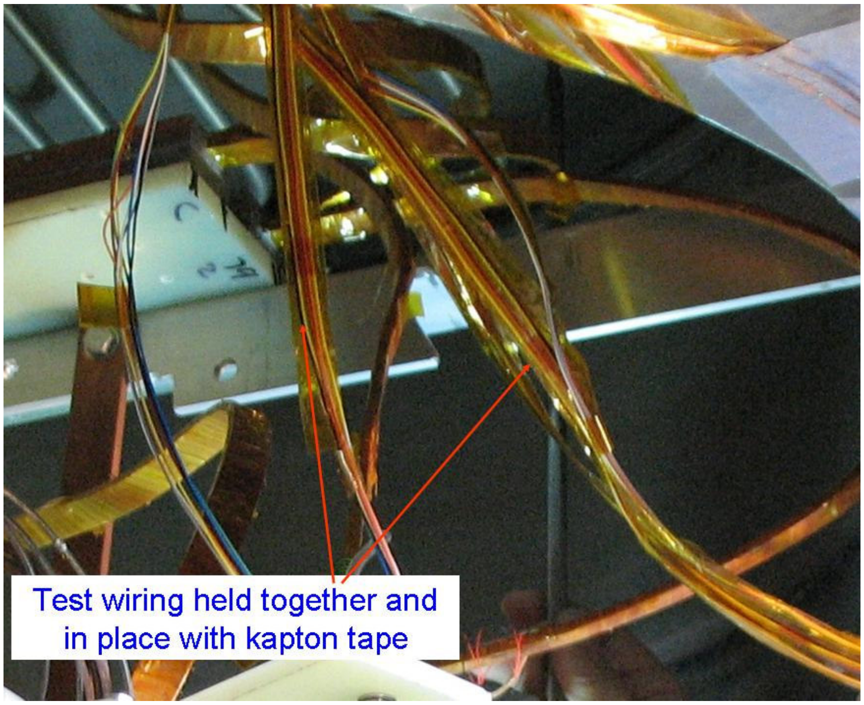


Figure 2: Close-up of Test Wiring Before Magnet Testing

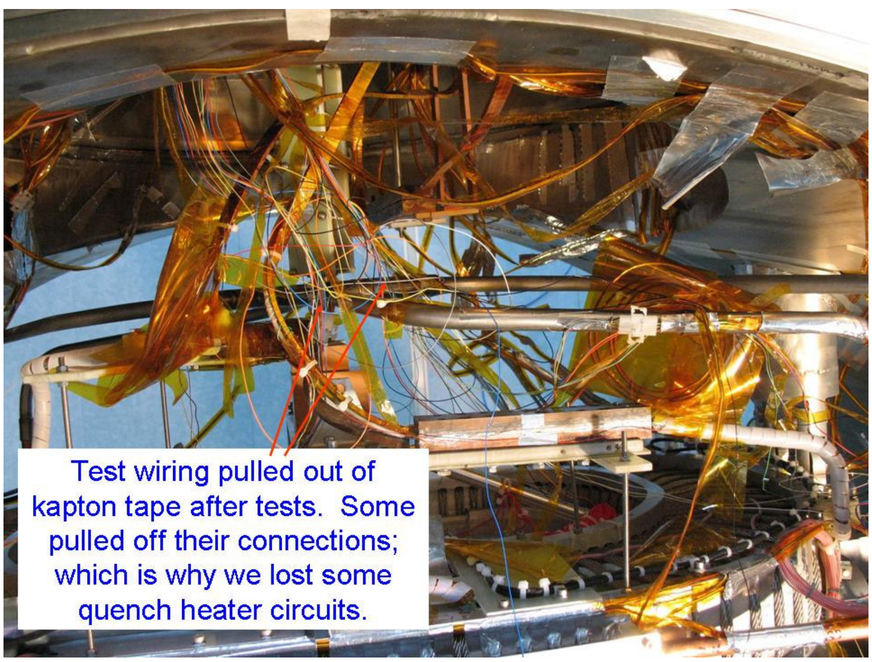


Figure 3: Test Wiring After Magnet Testing

Corrective Action: Flight systems were not directly impacted by this event, however actions were taken to assure that all wiring for the flight system has adequate restraints to prevent movement and pull-out of necessary electronic equipment and wiring.

Safety Impact: None. Even in the event that the quench protection system does not fire the quench protection heaters, any 'damage' to the magnet is not a safety concern. The tiny movements could be a concern for the mission success of the magnet, but pose no danger.

Status: Closed

SUPPORTING DOCUMENTATION: (None)

8. AMS-02-A08 – Failure Anomaly Report for DALLAS Temperature Sensors (DTS) in TRD-GAS Box-C Canister

Description of Event: Non functional DTS were observed when testing on Aug.15th 2007, before the welding of TRD-GAS Box-C Canister. Upon investigation it was determined that the supply voltage had been applied to the sensor with reversed polarity due to wrong Box-C canister internal cabling documentation.

Corrective Action: The DTS were replaced as they had been used out of the manufacturer's Absolute Maximum Rating (by applying reversed power which is limited in the manufacturer's specification to -0.5 V) and all documentation was corrected to note the correct polarization. Wiring corrected all DTS sensors worked per design.

Safety Impact: None. The DTS system is used to health maintenance and system performance, not safety.

Status: Closed

SUPPORTING DOCUMENTATION: (None)

9. AMS-02-A09 – Cryomagnet/Vacuum Case Burst Disk Post Vibration Test Anomaly

Description of Event: During post vibration testing, the burst disk assembly (of three series burst disks) was pressure tested to assure that it's performance met standards, that is that with the application of pressure in excess of the rupture value the sequence of burst disks would rupture allowing for venting. During testing the first (closes to pressure source) burst disk ruptures properly, but the second burst disk only partially opened, the third remained entirely intact. This effect was repeated on subsequent testing. Additional testing led to the understanding that the large low pressure burst disk was responding to a low energy shock wave that had sufficient pressure to begin a rupture, but insufficient energy to complete the rupture of the second burst disk. This phenomena appeared to be design specific, as it was no duplicated when the first burst disk was removed the second and third burst disks opened properly. The AMS-02 Project sent a request to the PSRP to establish if the triple burst disk design imposed at the AMS-02 Phase I Flight Safety Review was properly applied to the vacuum case burst disk configuration. With the PSRP representative's concurrence AMS-02 is proceeding with a revised design that utilizes a pair of burst disks in series not three.

Corrective Action: Fike is redesigning the entire vacuum case burst disk assembly using the lessons learned from this unique phenomena and configuration and will be re-qualifying the design.

Corrective Action of AMS-02-A09 is linked to Corrective Action to AMS-02-A10.

Safety Impact: An improperly functioning burst disk assembly could allow pressure to rise in the vacuum case in the event of a Helium tank rupture that leads to pressure build up in the vacuum case. This makes this a Safety Critical anomaly and the revised system will undergo all appropriate qualification testing.

Status: Closed. See AMS-02-A10

SUPPORTING DOCUMENTATION: (follows)

Engineering and Science Contract Group
2224 Bay Area Boulevard
Houston, Texas 77058

ESCG-4390-08-SP-MEMO-0002
9 January 2008

TO: Ray Rehm, Paul Mensingh, PSRP Executive Secretary

FROM: Chris Tutt, Leland Hill

SUBJECT: Review of Anomalous AMS-02 Burst Disk Test Results

Introduction

One of the primary scientific elements of the Alpha Magnetic Spectrometer (AMS-02) is a cryogenic, superconducting magnet. This magnet is enclosed in a dewar, the outer surface of which is referred to as the Vacuum Case (VC). The VC has a maximum design pressure of 0.8 bar, with overpressurization protection provided by burst disks. The disks use a reverse-acting circumferentially scored mechanism with cutting teeth. When the disk reaches burst pressure, the disk membrane reverses and the scored line presses against a cutting blade to induce a full rupture. This meets the standards of NASA/JSC TA-88-074 for single fault tolerance.

Originally, the system was designed with a single burst disk, which is typical for most high-performance cryogenic systems. At the Phase 0/I Flight Safety Review, the panel identified a new failure mode for the system. If the disk were to leak or spontaneously rupture within the atmosphere, air could enter the dewar's vacuum space. This would lead to a massive influx of heat into the tank of superfluid helium inside, which would cause it to rapidly warm up. As the helium begins boiling, the tank pressure would eventually rise to the burst pressure of the tank's burst disks and begin venting. If this were to occur during the point of maximum load during ascent, the Shuttle payload bay could be overpressurized. The panel therefore demanded a triple-redundant burst disk design to provide two additional levels of control against leakage. This arrangement is shown in Figure 1.

In the overall design, the original burst disk was called BD07, so in the new design, the disks were named BD07A, BD07B, and BD07C. Because the disks have a design burst pressure less than atmospheric pressure, vent lines have to be added to the interspaces between the individual disks to allow the air sealed in the tubes during manufacturing to escape. Otherwise, disk B and C would rupture when the outside atmosphere during ascent reached 0.2 bar. Given the small air volumes behind the disk, this would almost certainly lead to an incomplete rupture, which would prevent the assembly from providing the required overpressure protection. In Figure 1, these vent lines are shown as rising 90-degree bends from the interspaces.

FORM ESCG 002A-1 (06/26/2006)

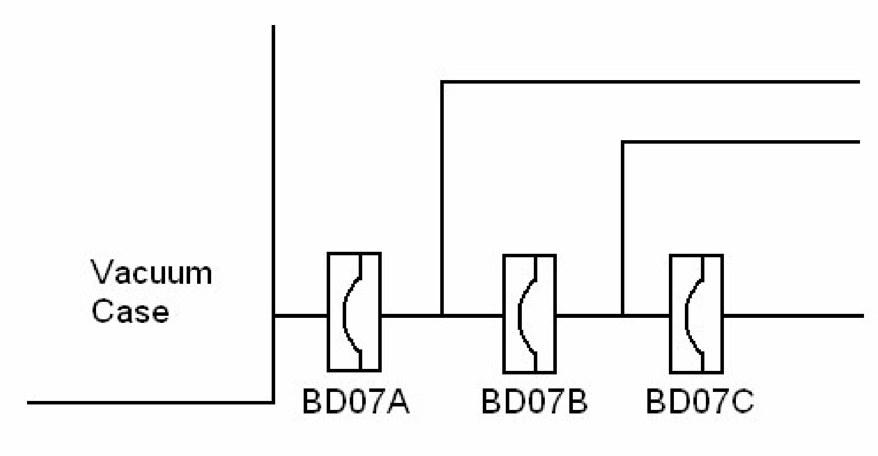


Figure 1: Vacuum Case Burst Disk Schematic

The triple disk assembly was designed and manufactured by the Fike Corporation based on the schematic in Figure 1. The main vent channel has a large flange with redundant O-ring seals where the assembly bolts to a port in the VC. Figure 2 shows a section through the assembly. The small holes in the interspaces are the 0.25" OD vent lines, while the two 2.688" through holes are the zero-thrust vents for the exhaust.

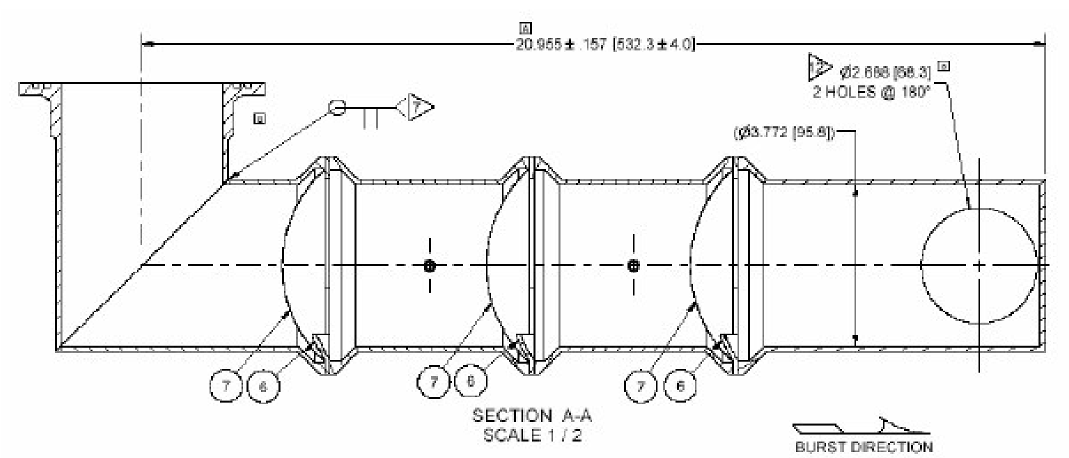


Figure 2: Burst Disk Assembly Design

Test Anomaly

As described in the burst disk qualification plan (SCL Memo #2484), three qualification units will be built and burst for each flight unit. Originally, there were to be two flight VC burst disk assemblies delivered: one for the flight unit and one for the structural test article (STA), which was to have a working cryosystem. Six qualification units were therefore built, along with a flight spare. The STA cryosystem was later removed from the design, so that unit became a second flight spare. The order with Fike had already been placed at this point; therefore all six qualification units were made. These will be referred to subsequently as Units 1-6, while the flight spares will be referred to as Units 7 and 8. This plan was presented in the Phase II Flight Safety Review package and was approved by the panel at that time.

For qualification testing, each test unit was attached to a large pressure vessel filled with gaseous helium. Pressure in the space behind BD07 was allowed to rise slowly to the design burst pressure, at which point all three disks should have burst. The setup is shown in Figure 3.

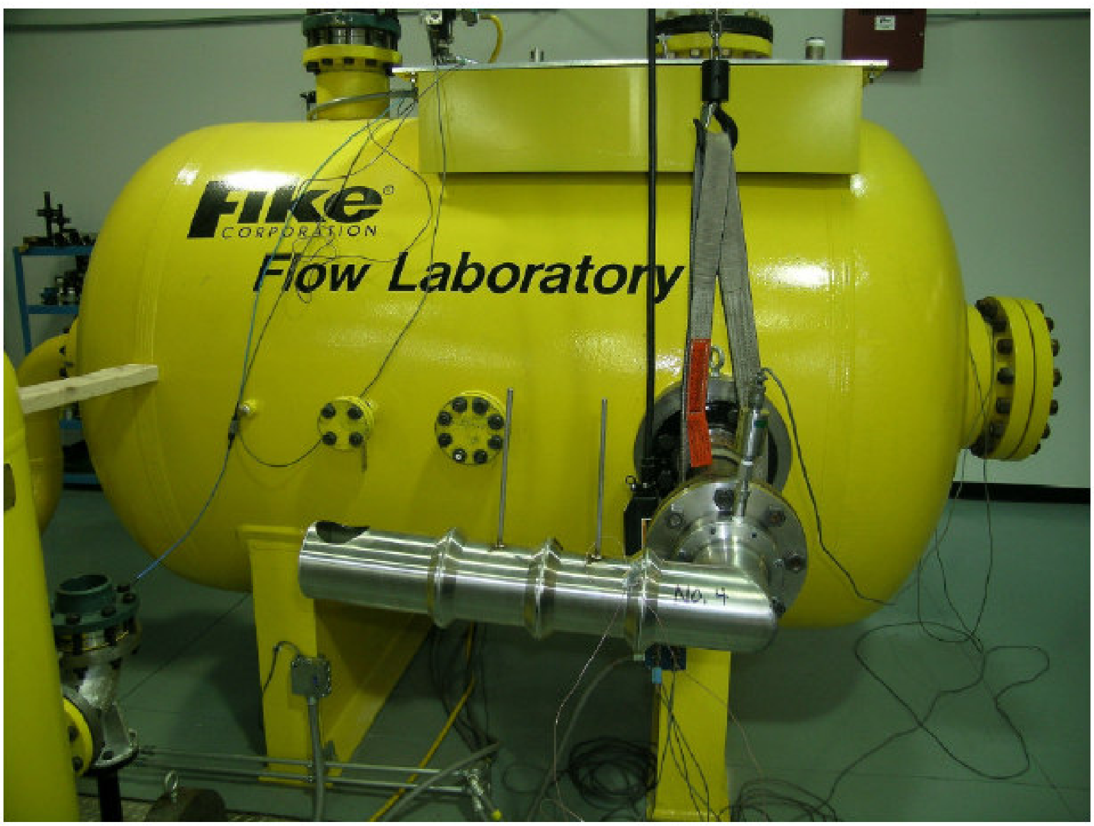


Figure 3: Qualification Test Setup

In the qualification burst of Units 1-4, BD07A ruptured normally, but BD07B failed to fully open. The disk membrane appeared to reverse, but did not fully tear. (This was confirmed when Unit 1 was cut open for a visual inspection of the disk, shown in Figure 4.) Airflow through BD07B was restricted enough that all air passing through simply vented through the interspace vent line. Air flow into the test volume was shut off at the sound of the event, preventing a renewed pressure rise.

Figure 4: Incomplete Tear of BD07B

During the test of Unit 4, pressure taps recorded data at the inlet of BD07A and the interspace between BD07B and BD07C. The pressure data for the BD07A inlet is shown in Figure 5. Immediately after burst, there is a series of wide pressure oscillations ranging over nearly 3 psig at approximately 20 Hz. The cause of this oscillation is not immediately clear, but it is the likely cause of the anomalous behavior. The first spike at 12 psig is more than enough to reverse disk BD07B, but since it drops to less than 9 psig within approximately 0.05 seconds, there may not be enough energy to completely tear the disk along the score line. (The pressure measurements in the BD07B/C interspace did not show these oscillations.)

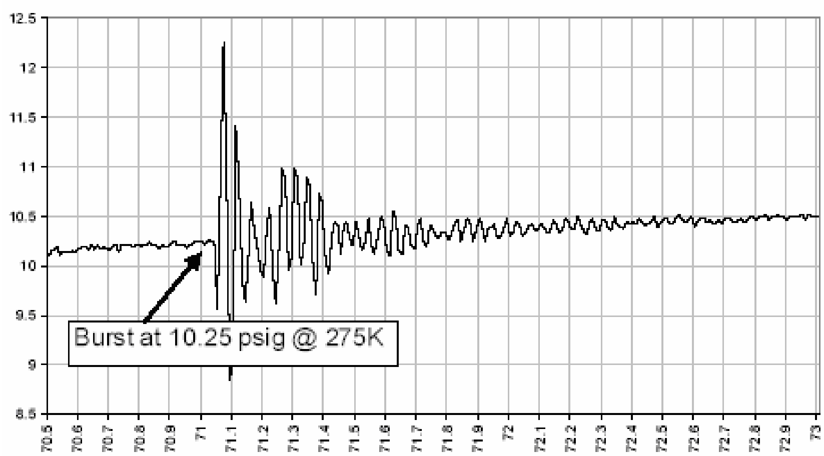


Figure 5: Pressure v. Time for Unit 4 Qualification Test

After further discussion, Fike mechanically cut out BD07A in Unit 5 and subjected disks B&C to a qualification burst. Unit 5 operated nominally, with both disks operating exactly as designed. Pressure taps in the new VC/BD07B interspace did not record any oscillatory behavior similar to Figure 5.

While the root cause of the pressure oscillation has not been completely determined, it is most likely a shockwave-related event caused by the 90-degree bend in the assembly tube just prior to BD07A. This would explain why the anomalous results occurred in Units 1-4 but not in Unit 5, where the initial burst surface was much further away from the bend.

In addition to these tests, Units 1 and 4 were tested a second time to see if the second disk would eventually rupture nominally if repressurized to the design burst. In both cases, BD07C burst normally, but BD07B remained in the partially torn condition.

Proposed Modification

The anomalous test results clearly require a change in the overall design of this assembly, but because of the advanced stage of payload manufacturing and design, the goal is make the modifications as simple as possible. The project's proposal is to remove BD07A from all remaining assemblies using a similar process to what was done for Unit 5. The vent line for the BD07A/B interspace would be crimped and welded shut as well. The flight system would then look exactly like Unit 5, which has undergone a successful qualification test. Units 6 and 7 would also undergo qualification bursts to give the 3:1 test ratio mandated in the burst disk verification plan. The new schematic is shown in Figure 6.

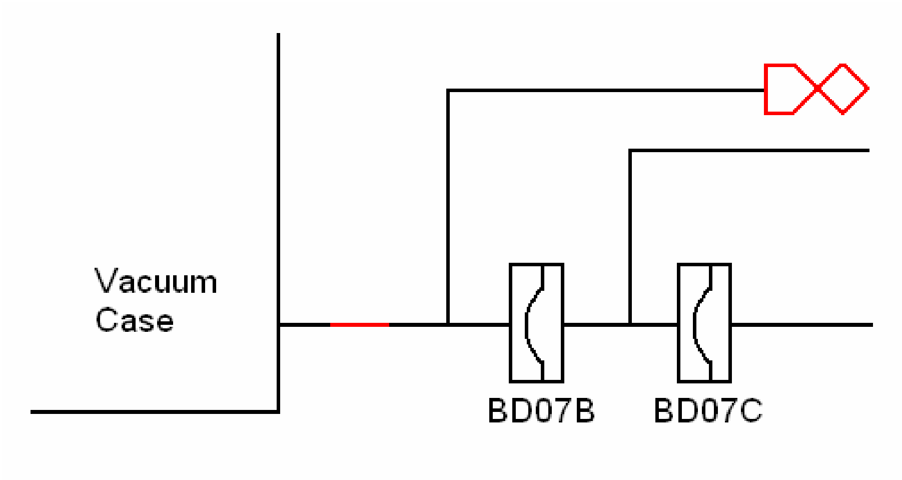


Figure 6: Proposed VC Design Modification

This may seem to remove one level of safety control in the design, but in fact it has no bearing on the risk of leakage through the assembly discussed in the previous section. As shown in Figure 1, there was always a potential leak path through the vent tube in the BD07A/B interspace if a leak were to develop in BD07A. This potential leakage has already been assessed against the maximum credible leak used in the overall VC design and found to be encompassed by the existing analysis. In the new system, the potential leak path is through BD07B instead of BD07A, but this has no bearing on either the safety acceptance rationale in the overall safety analysis or on our compliance with it.

Memorandum

(Continued)

In order to exceed the existing analysis, both BD07B and BD07C would have to spontaneously fail fully open, allowing air to rush in through the full-sized vent orifice. The only potential causes of a spontaneous failure would be launch vibration or material corrosion. These scenarios are not credible for several reasons:

1) The disks are made of 316 series stainless steel, a standard Class I aerospace material with no history of spontaneous corrosion if treated properly.
2) All six qual units were vibration tested to acceptance vibration levels. None of the disks (18 in total) failed post-test leak checks.
3) Neither burst disk is designed to burst from the outside. As shown in the retests of Units 1 and 4, once the disk has reversed and even partially torn, it sustained a pressure of approximately 0.8 bar without fully opening. Outside air pressure above 1.8 bar psia is clearly not credible.

The project therefore feels that the proposed design change does not in any way affect the overall safety of the AMS-02 VC and thus should present no concern to the Payload Safety Review Panel.

9. AMS-02-A10 – AMS-02 Super Fluid Helium Tank BD03 Duct Excessive Thermal Conductance

<u>Description of Event:</u> During developmental work on the flight hardware for the duct that takes any released gas/liquid from the BD03 (3 bar) on the superfluid helium (SFHe) tank to the BD06A-B (2, 3 bar) in the port of the vacuum case, the thermal conductivity and inability to block heat radiation of the fiberglass duct was found to be unacceptable and work to develop an alternative means of conducting effluence from the SFHe Tank through to the exterior of the AMS-02.

During development a collapsed Kapton tube was developed and tested to substitute, this tub could be “pinched” to eliminate radiation cooling and the thermal conductivity was acceptable.

Testing had proceeded with a “fast” valve substituting for the BD03 element, and the activation time for this valve was ~200 milliseconds.

Testing with an actual burst disk however yielded unexpected results in the test setup. The tube was ruptured unexpectedly.

Burst disk pressurization does not take place over ~200 milliseconds, but ~ 4 milliseconds, creating a more distinct pressure wave that the tube had to endure.

Additionally for the only time in testing of the BD03 design, the membrane detached from the burst disk.

It is not established if the pressure spike or the travel of the membrane through the fabric tube was the specific cause of the dissolution of the tube’s integrity. The tube’s design was rejected and a new “telescoping” fiberglass design was created with additional super insulation and a aluminum “petal” shield for heat radiation blocking. The term “telescoping” refers to the method of installation, not operation of the tube.

The disconnection of the membrane from the burst disk has been attributed to a design error in the test set up where the tube immediately downstream of the burst disk was smaller than specification from the BD manufacturer. This provided a fulcrum by which the membrane was left in the gas flow, the curving surface enhancing the “tear” through the hinge area of the membrane.

<u>Corrective Action:</u>

The Tube from BD03 has been redesigned to have sufficient static and dynamic pressure loading characteristics and sized to not induce severing of the burst disk membrane. Rather than exiting through a single BD on the vacuum case ring, it will now exist through two four inch burst disks that will open at 0.8 bar, the same as the vacuum case pressure relief. This is accomplished by turning the prior evacuation port for the duct into another burst disk location and making the duct “leaky” so that during vacuum case evacuation, the tube is evacuated as well.

This design change also removes the "layers" of serial burst disks as being more reliable in providing overpressurization protection as discovered in response to AMS-02-A09. A single 0.8 bar burst disk now exits at each of the BD06 ports and the BD07 port that is dedicated to protecting the overpressurization of the vacuum case. This design change was presented to the PSRP at a technical interchange meeting on August 13, 2009 and the design modification accepted by the PSRP.

Safety Impact:

The pressure relief system has been revised to be more reliable, provide additional venting area for the SFHe tank and reduce the thermal conductivity into the SFHe tank increasing the longevity of the AMS-02 Mission. While the latter is mission success, the former is clearly safety related making this anomaly safety critical.

Status: Closed, final testing of new design of BD03/BD06 duct and burst disk design completed at Texas A&M University successfully.

SUPPORTING DOCUMENTATION: (follows)

Alpha Magnetic Spectrometer SFHe Tank Burst Disk Design Change

Prepared by
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NASA AMS Project Manager
281-483-3296
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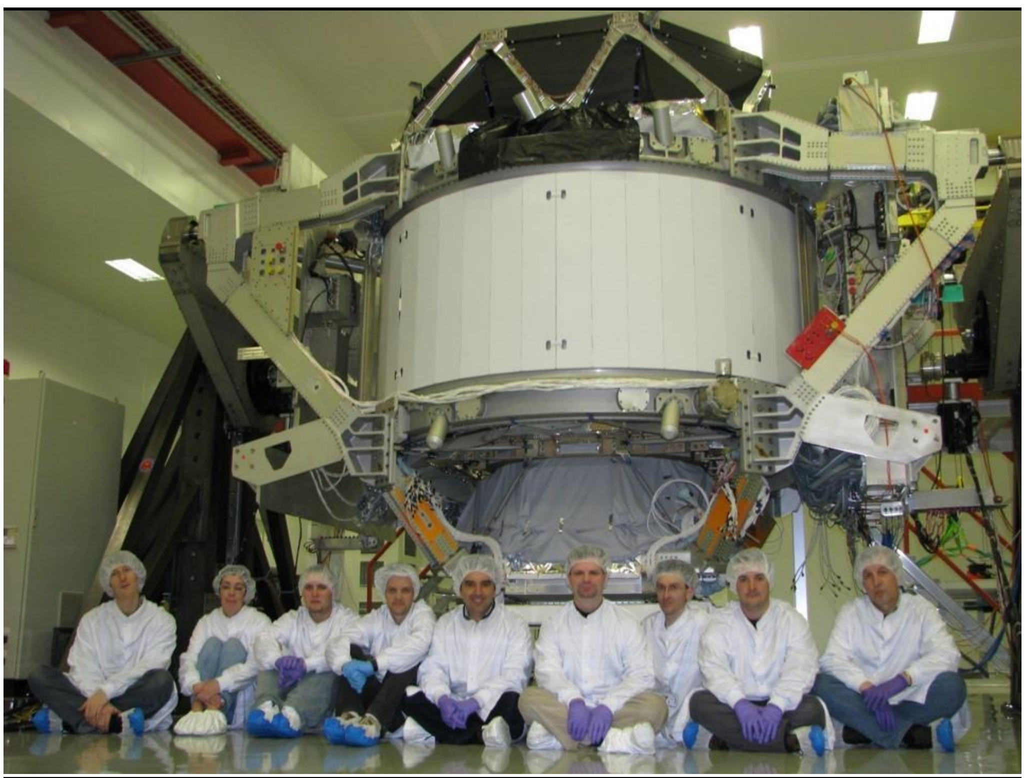
Prepared
10 August 2009



History

- AMS Phase II FSR was May 2007
- Data Package can be found at:
  - http://ams-02project.jsc.nasa.gov/html/SDP.htm
- Current design of AMS Dewar Burst Disks coordinated through numerous meetings with EP and PSRP over the last 8 years

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Current Design

- Current design includes
  - Double 0.8 bar burst disk in series on Vacuum Case (BD07A and B) with the volume between them referenced to the surrounding atmosphere through a weep hole
  - Single 'cold' (2 K) 3 bar burst disk welded to SFHe Tank (BD03)
  - Ducted path from 'cold' to 'warm' (300 K)
  - Double 'warm' burst disk assembly with 3 bar burst disk (BD06A) at VC interface and 2 bar burst disk (BD06B) in series just outside of 3 bar disk. The space between BD06A and BD06B is evacuated and sealed.
  - Zero thrust vent outside of all burst disk assemblies

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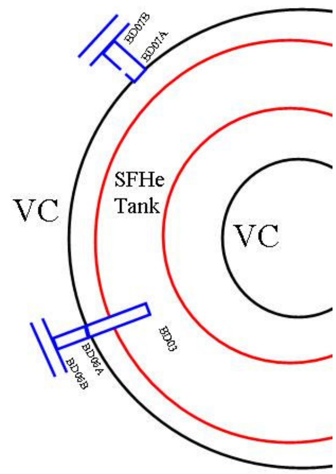
Current Burst Disks

- The existing burst disks on the SFHe Tank and the VC have the following specifications:
  - BD03 on a re-entrant tube welded directly to the SFHe Tank: 3 bard +0/-10% at 1.8K (2.7 to 3.0 bard)
  - BD06A on the VC exterior at exit of ductwork from BD03, but referenced to VC vacuum space: 3 bard +0/-10% at 295K (2.7 to 3.0 bard)
  - BD06B on the VC exterior on the evacuated exit of BD06A: 2 bard +0/-10% at 295K (1.8 to 2.0 bard)
  - BD07A on the VC exterior to the vacuum space: 0.8 bard +0/-30% at 295K (0.56 to 0.80 bard)
  - BD07B on VC exterior at exit of BD07B but referenced to the external atmospheric pressure: 0.8 bard +0/-30% at 295K (0.56 to 0.80 bard)



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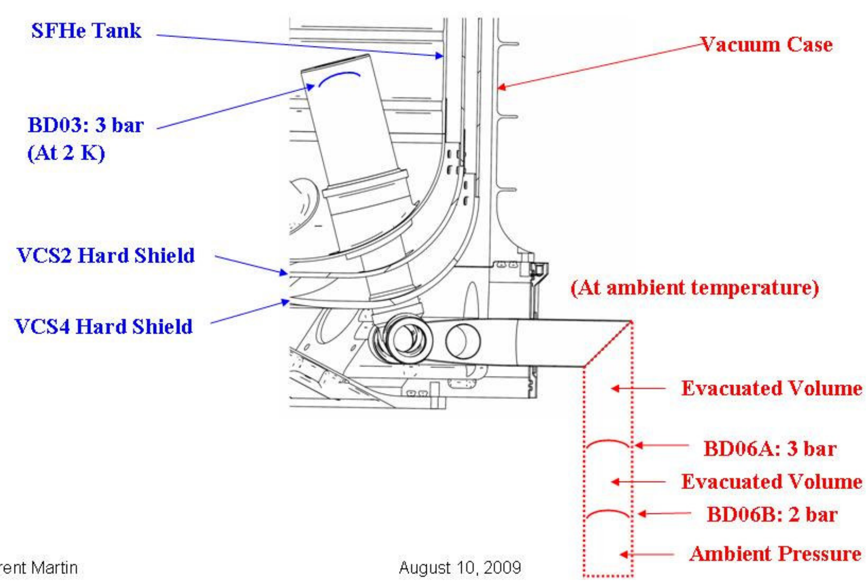
General Arrangement of BD03 and BD06A/B from the SFHe Tank through the VC



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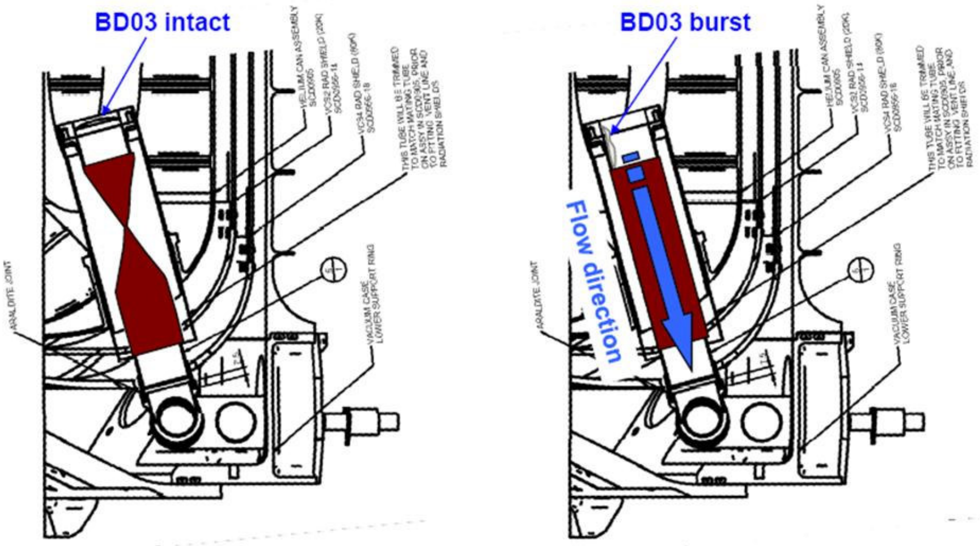
Existing Kapton Duct configuration



Kapton Vent Duct collapsed

Kapton Vent Duct inflated

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AMS Magnet

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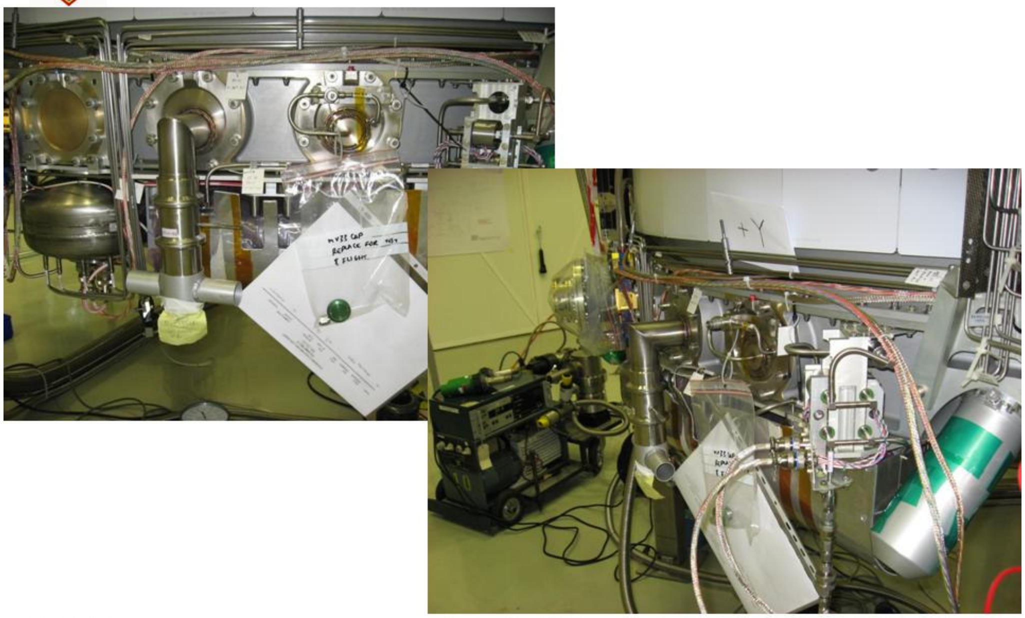
BD06 with Zero Thrust Vent



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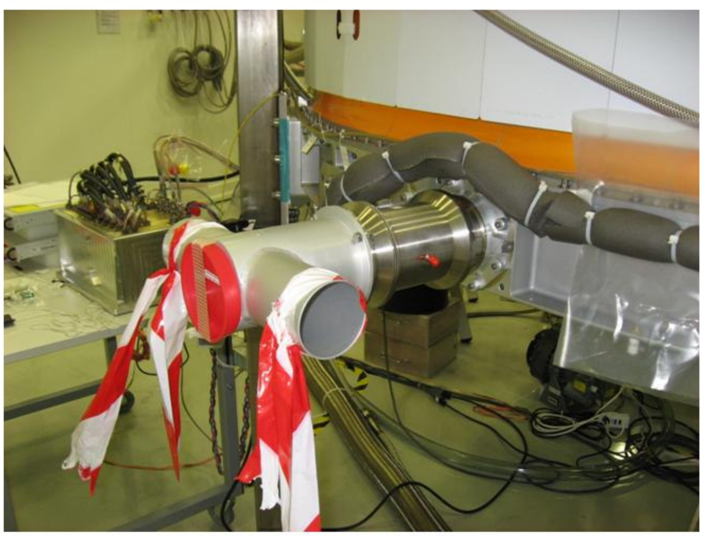
BD07 with Zero Thrust Vent



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Design Considerations

- **Safety**
  - **Over Pressurization** - Option chosen must prevent the SFHe tank from being over pressurized (3 bard) while at the same time must prevent the VC from being over pressurized (0.8 bard)
  - **Flexibility** - Option chosen must be flexible enough to take the entire spectrum of transportation, differential thermal expansion/contraction, and launch deflections with one end at ~2K and the other at ~300K for the entire life of the cryostat
- **Mission Success**
  - **Thermal Conduction and Radiation** – Option chosen must minimize thermal conduction and radiation with one end at ~2K and the other at ~300K. This is in order to meet mission requirements for helium endurance
  - **Configuration Compatibility** - Option chosen must be compatible with the existing configuration of BD03 on the SFHe tank and the available ports on the VC as well as the configuration of the BD03 qualification tests that have already been performed
  - **Schedule** – Self explanatory, STS-134 scheduled for July 29, 2010
  - **Costs** - AMS Project resources are limited, and getting new contracts in place quickly is difficult

Testing on Existing Design

- All of the burst disks have gone through extensive testing
  - Acceptance testing (lot burst testing on individual burst disks and on assemblies if in series)
  - Vibration testing (on assemblies)
  - Leak testing (on individual burst disks and as assemblies)
- The existing flexible/collapsible Kapton duct configuration was tested extensively using a ~250 liter volume and a ball valve venting 'rapidly' via a 40 mm diameter transfer line ~3 meters long into a representative flexible/collapsed and offset duct partially submerged in liquid nitrogen (LN2)
  - This development test program took ~5 months to develop the configuration currently installed on the flight magnet
  - Although numerous failures were encountered during the development program, the final version was finally shown to work repeatedly with rapid pressurization to ~6 bard. 'Rapid' in this case means pressurization in a fraction of a second (~200 milliseconds). With these successful tests, the magnet developer installed this version into the flight magnet.

Testing of Existing Design, Cont.

- While work progressed on the flight system, a test was prepared to test the final configuration as a complete assembly
- Previous successful tests of components within the assembly gave the magnet developer confidence that the final test would be successful

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Development Tests of Kapton Tube

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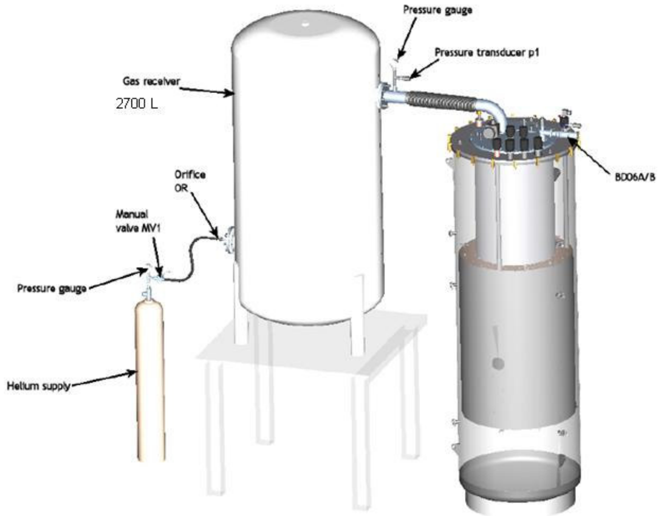
Test Setup for Existing Design



- A test rig was designed and constructed which allowed the flight spare disks to be mounted at the end of a 2.7 m3 volume which could be pressurized to 3 bar or higher.
- Gas in the system was warm, but a heat exchange with liquid nitrogen bath was included so that the inner disk (BD03) could be cooled to a temperature of 77K.

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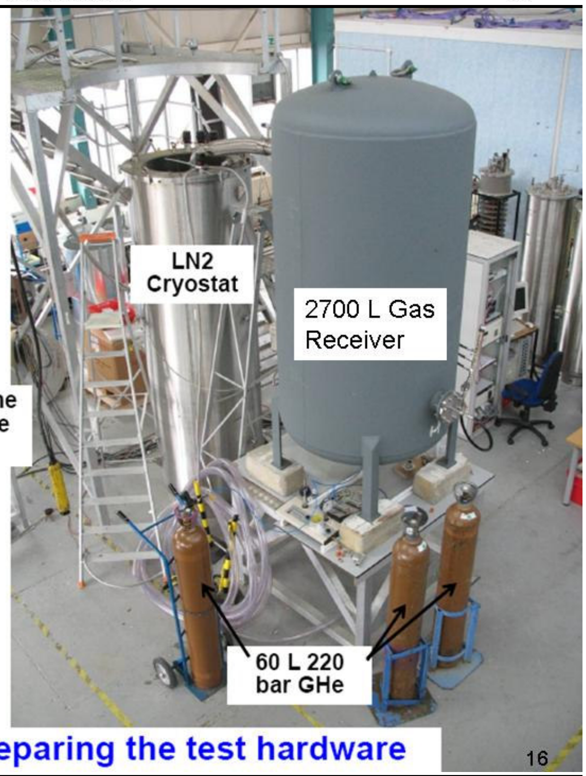
Installing the superinsulation around the LN2 torroidal vessel that surrounds the BD03/Kapton Tube assembly



Preparing the test hardware

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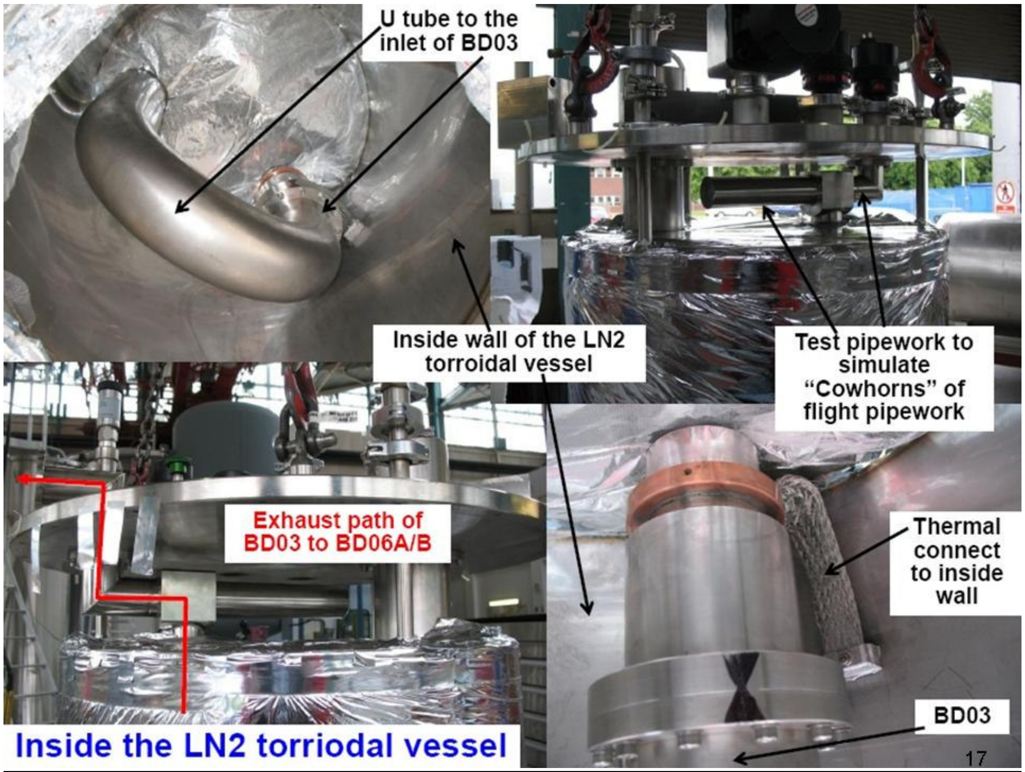
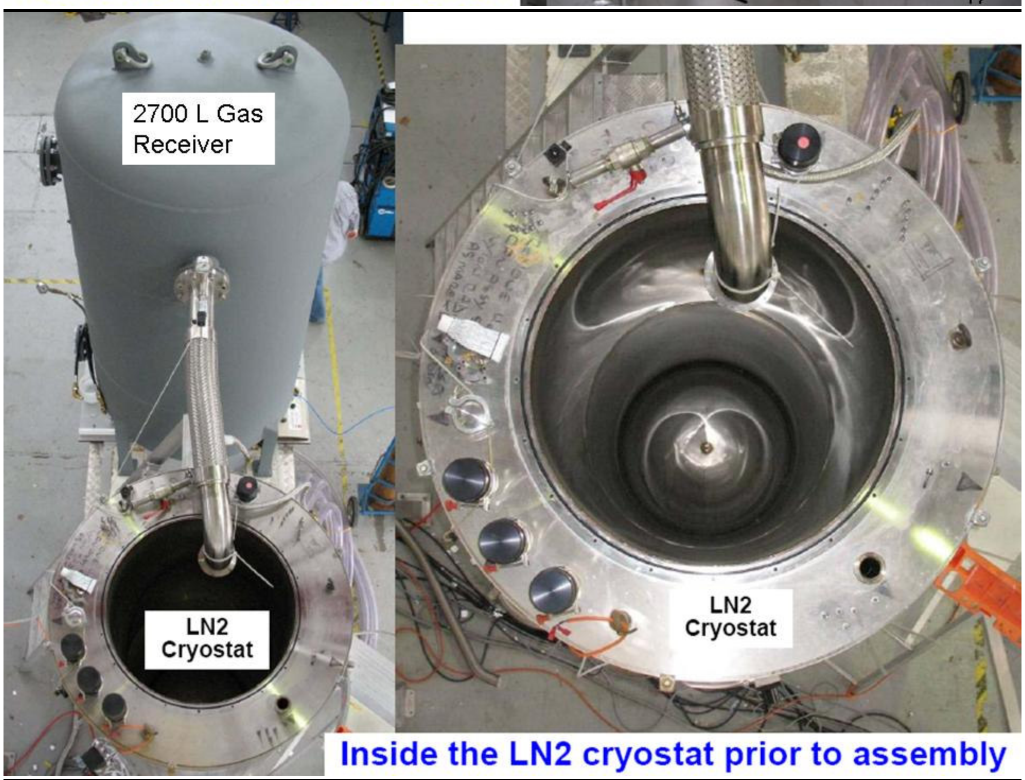

U tube to the inlet of BD03
Inside wall of the LN2 torroidal vessel
Test pipework to simulate "Cowhorns" of flight pipework
Exhaust path of BD03 to BD06A/B
Thermal connect to inside wall
BD03
Inside the LN2 torriodal vessel
17


2700 L Gas Receiver
LN2 Cryostat
LN2 Cryostat
Inside the LN2 cryostat prior to assembly

Test Rig Commissioning

- Due to limited number of spare burst disks, the test rig was first commissioned using relief valves.
- Main purpose of the commissioning was to determine how quickly the system could be pressurized to ensure that it match expected flight configuration
- Helium gas from the cylinder is allowed to fill the gas receiver.
- Flow rate is limited by an orifice.
- From receiver, helium also pressurized.
- When pressure in the receiver reaches 3 bar, a fast acting valve (SV on the diagram) opens to depressurize the system through a series of relief valves
- Preliminary tests showed that a single gas bottle was not sufficient to pressurize the receiver at a rate similar to expected flight magnet conditions. Also, a single bottle exhausted more completely than anticipated, so there was little driving pressure by the time the receiver reached 3 bar. For this reason, three gas bottles were connected in serious with a 5 mm orifice in the supply line to the receiver.
- The receiver was also slowly pressurized to 2 bar before the test rather than starting from vacuum.

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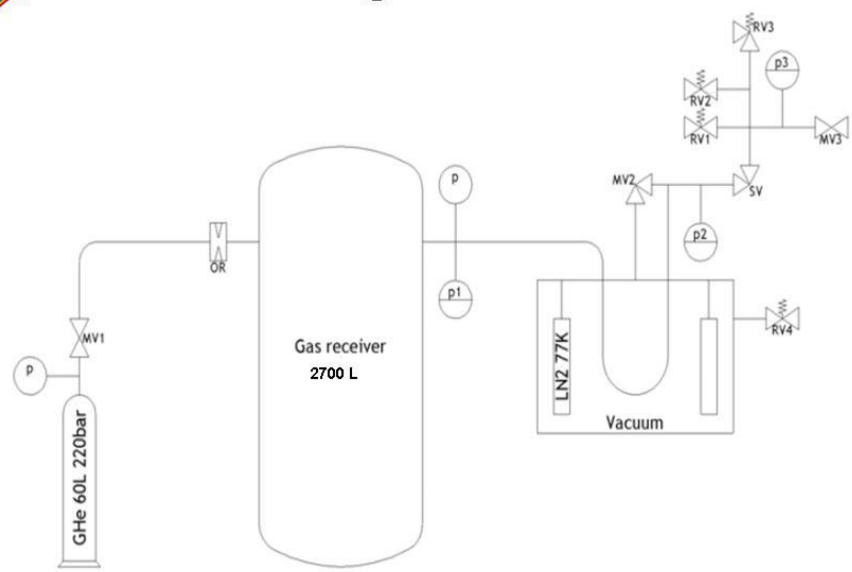
Test Rig Schematic



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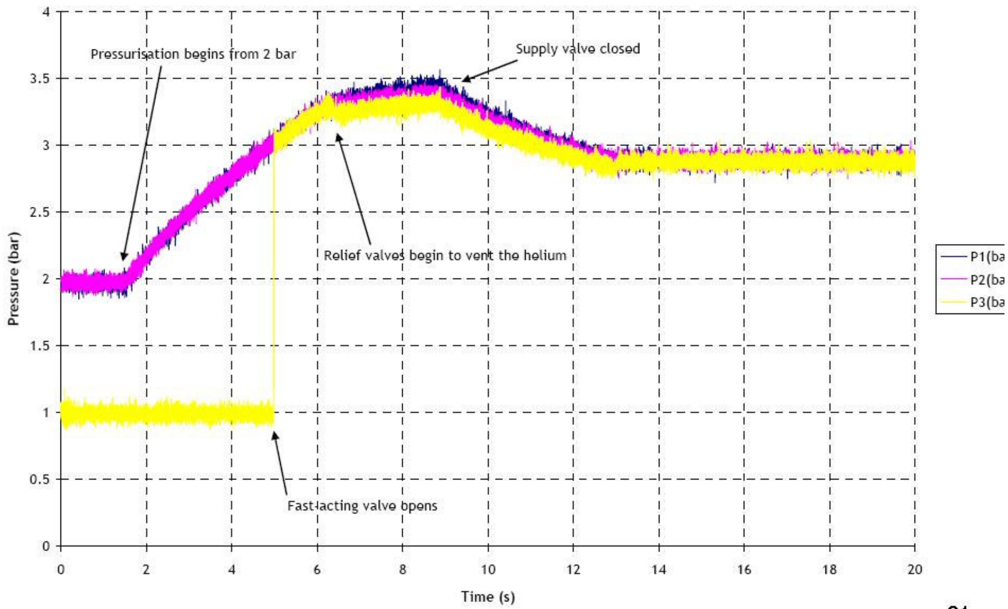
Test Rig Commissioning



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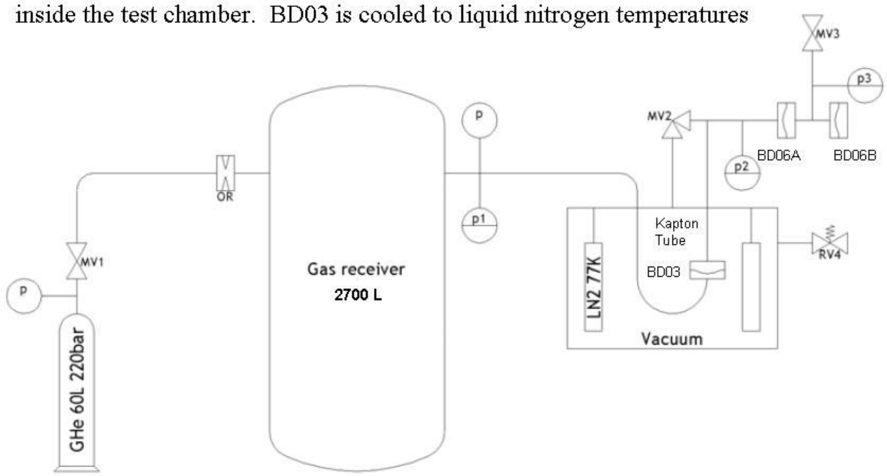
Burst Disk Test

- After commissioning, a set of spare flight burst disks were installed in the system and the arrangement was configured as shown here.
- In this configuration, a 4 inch line from the gas receiver now encounters BD03 inside the test chamber. BD03 is cooled to liquid nitrogen temperatures



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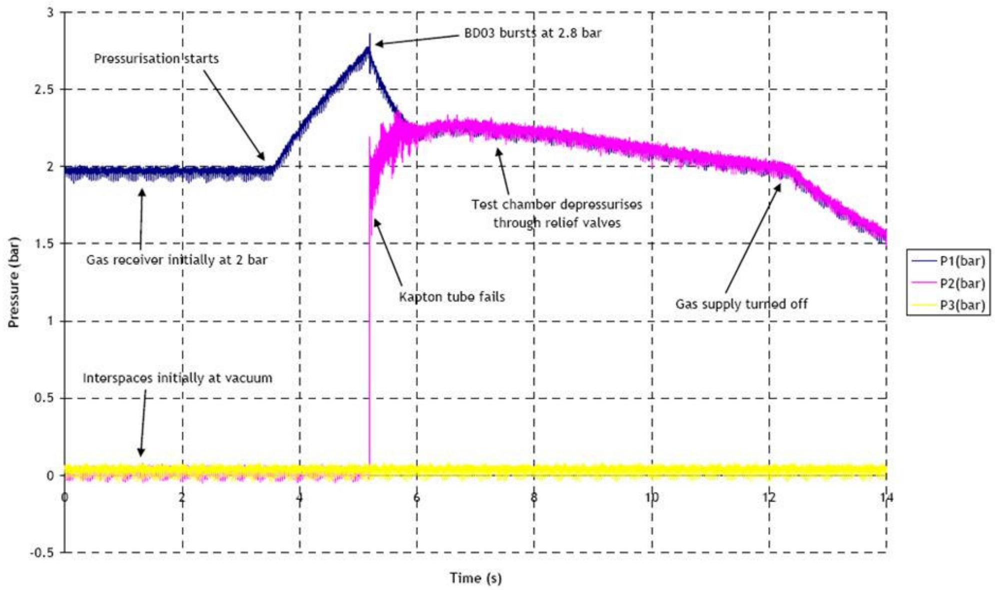
Burst Disk Assembly Test Results



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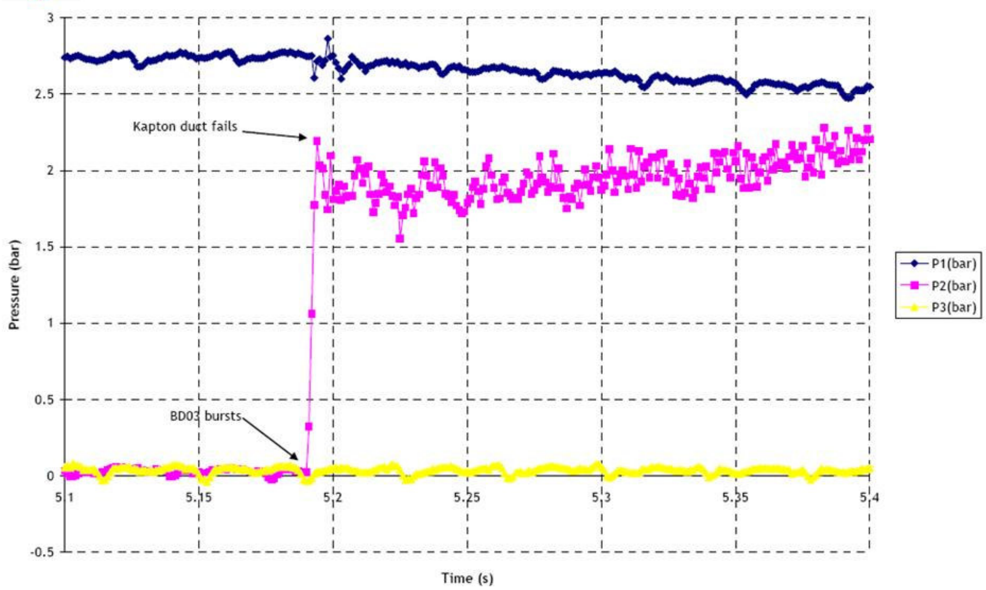
Burst Disk Assembly Test Results



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Test Failure

- Despite successful development tests of the Kapton tube, the tube experienced a failure during this 'final' test.
- The spare BD03 membrane disengaged during the test.
  - Although we have tested a large number of BD03, we have never experienced this failure mode in the past

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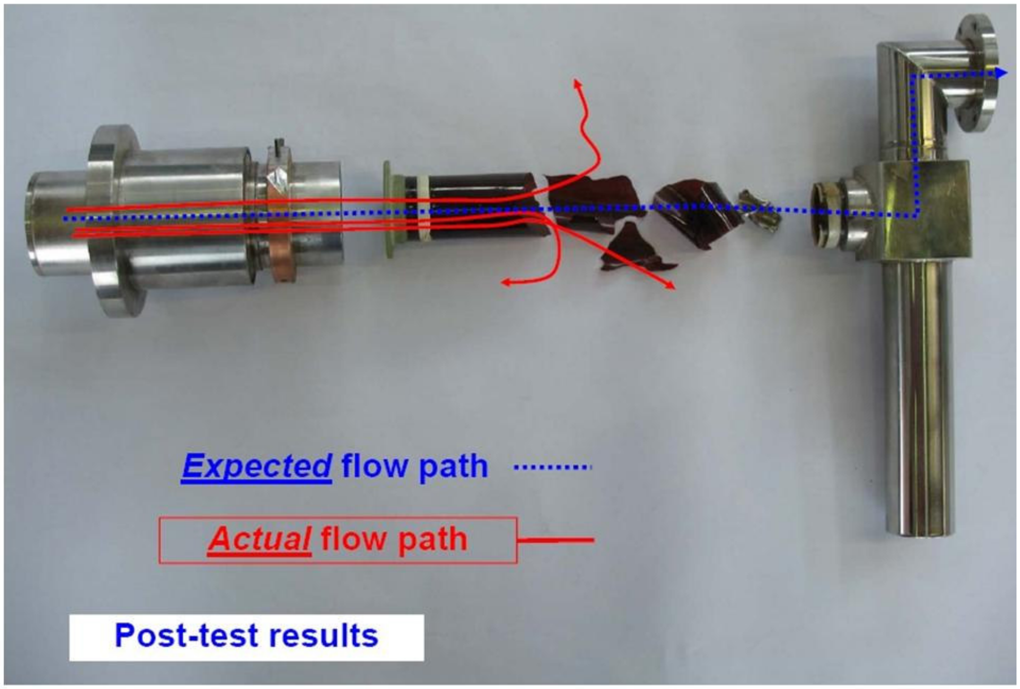

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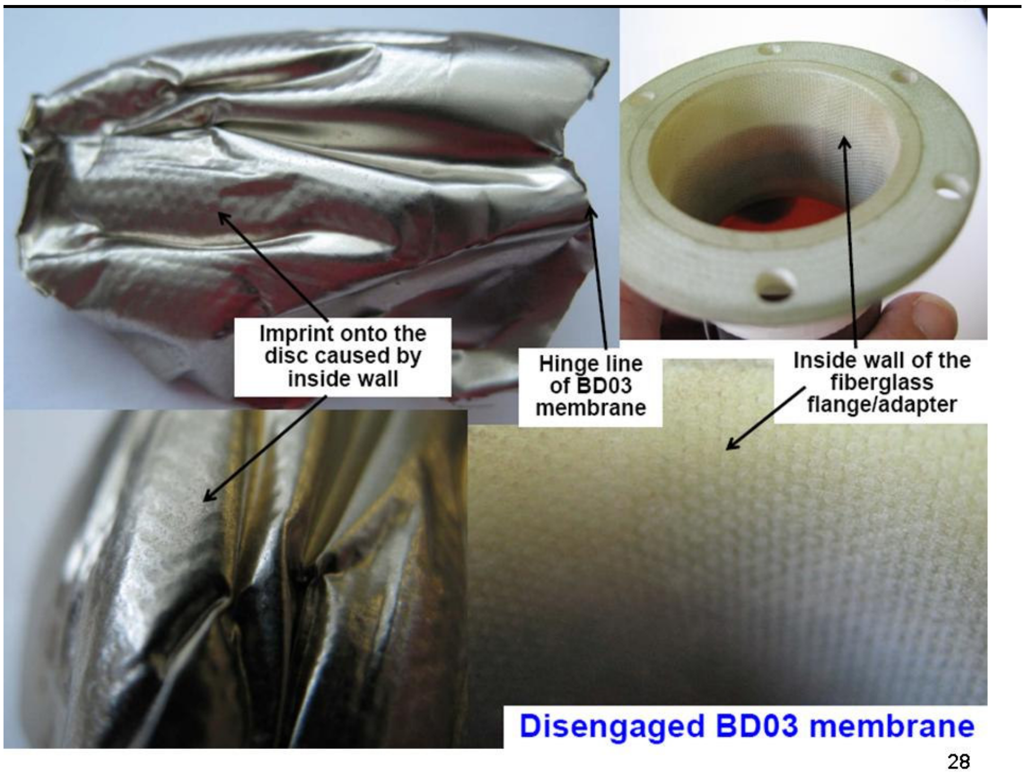
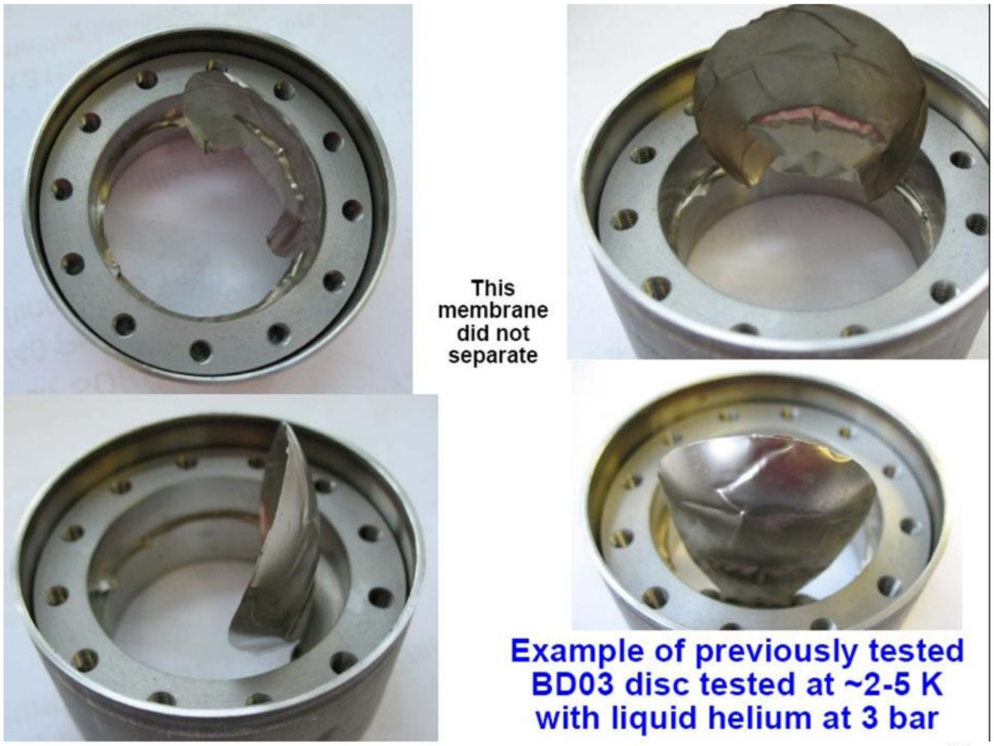
Hinge line
of BD03
membrane
Disengaged BD03 Membrane
27


Imprint onto the
disc caused by
inside wall
Hinge line
of BD03
membrane
Inside wall of the
fiberglass
flange/adapter
Disengaged BD03 membrane
28



Example of previously tested BD03 disc tested at ~2-5 K with liquid helium at 3 bar

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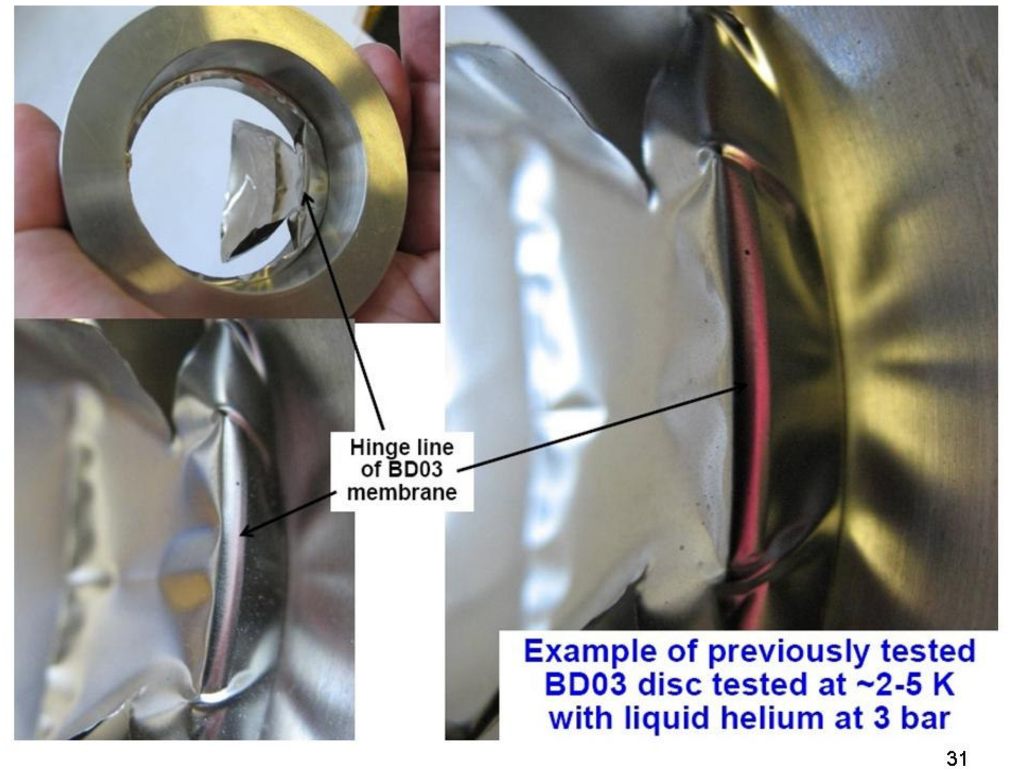
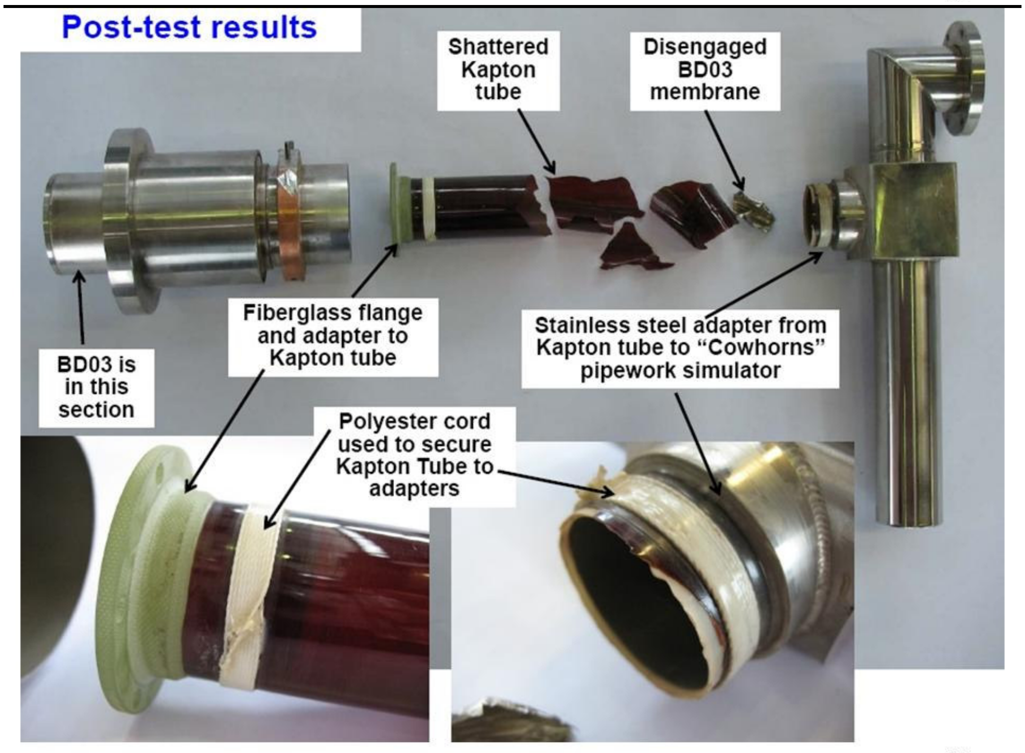

Hinge line
of BD03
membrane
Example of previously tested
BD03 disc tested at ~2-5 K
with liquid helium at 3 bar
31


Post-test results
Shattered
Kapton
tube
Disengaged
BD03
membrane
BD03 is
in this
section
Fiberglass flange
and adapter to
Kapton tube
Stainless steel adapter from
Kapton tube to "Cowhorns"
pipework simulator
Polyester cord
used to secure
Kapton Tube to
adapters
32

Test Failure Investigation

- Since the test on July 9, 2009, the following has been determined
  - Failure of the burst disk membrane is believed to have been caused by a design flaw in the fiberglass flange used to attach the Kapton tube to the BD03 assembly. The flange, which was supposed to be at least the same diameter as the burst disk opening was actually 6.6 mm smaller diameter than the disk opening. This caused the membrane to impale itself onto the fiberglass flange, weakening the hinge line and causing the membrane to detach.
  - Kapton tube failure could have been cause by the disk membrane impact or by the difference in the dynamic burst mechanism. All original tests were conducted with a pressurization rate of about 0 to 3 bard in 200 milliseconds. The burst disk rupture pressurizes the Kapton tube in about 4 milliseconds. The dynamic impact of this difference could have been enough to rupture the Kapton tube.
  - A finding unrelated to the failure is that the original design had a heat load much higher than expected, and any new proposal should at least attempt to rectify this problem.

How do we proceed?

- After the test and investigation, the AMS team has developed a go-forward plan that we plan to prove:
  - meets all of the design requirements,
  - will be tested to be shown to be a robust safety system, and
  - can be built and installed into the existing flight system quickly.

New Design Proposal

- Eliminate the Kapton Tube as it has been the source of weakness in the design and we can not guarantee that we will not experience similar failure in subsequent tests
- Replace the Kapton Tube with a composite telescoping structure which should be much more robust
- Replace the existing internal T-Duct (Cow Horns) with a new T-Duct system that thermally isolates and provides redundant paths to new external burst disks
- Replace BD06A/B assembly with two larger lower burst pressure burst disk in parallel. Since BD07 has already been qualified and meets these criteria, several single BD07 assemblies have been ordered for testing and final flight configuration. Reducing the burst pressure on the external disks should only make the design more safe and doubling the number and diameter, thus increasing the vent area by a factor of ~4 of the external burst disks will help ensure adequate vent area. Testing has been performed to show that the burst disks do not leak, but additional testing can be performed to show that if they do leak the safety system will still function.
- Implement additional radiation barrier made of one layer of 0.3mm thick pure aluminum to help dramatically improve the thermal performance of the system
- Perform a series of tests to show that this new configuration functions properly even under or beyond worst case safety conditions

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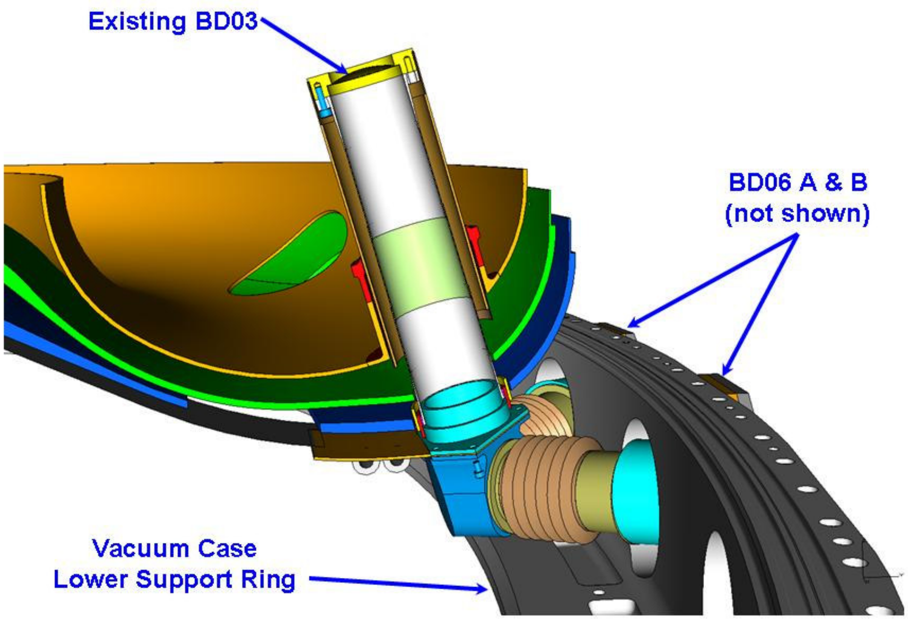
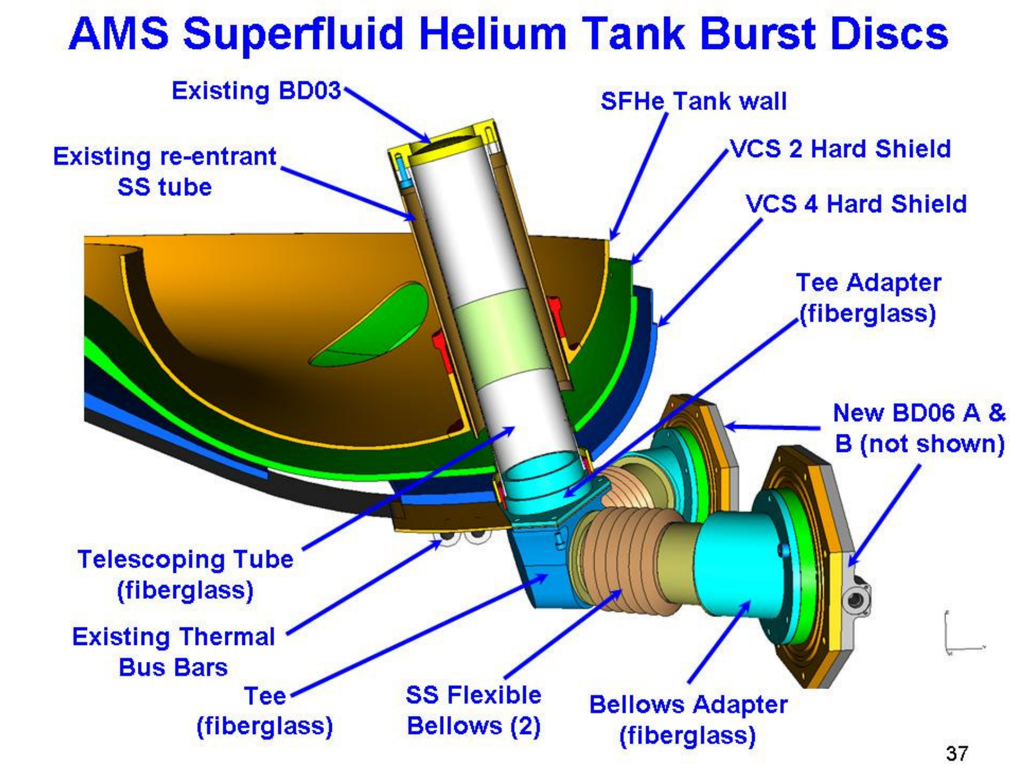
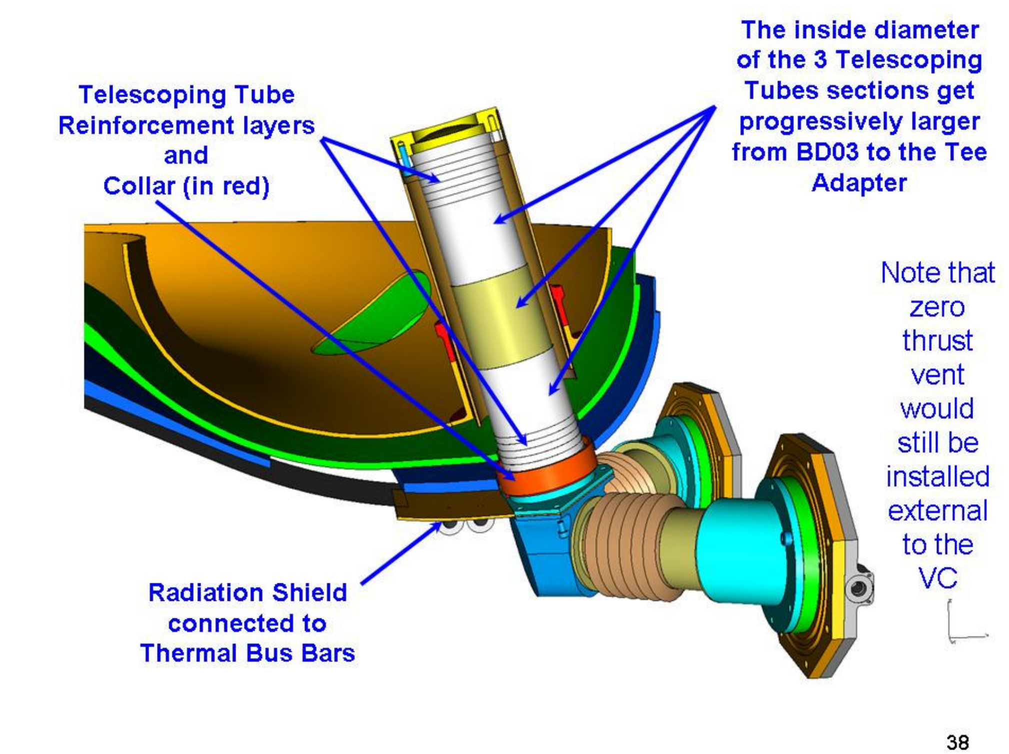
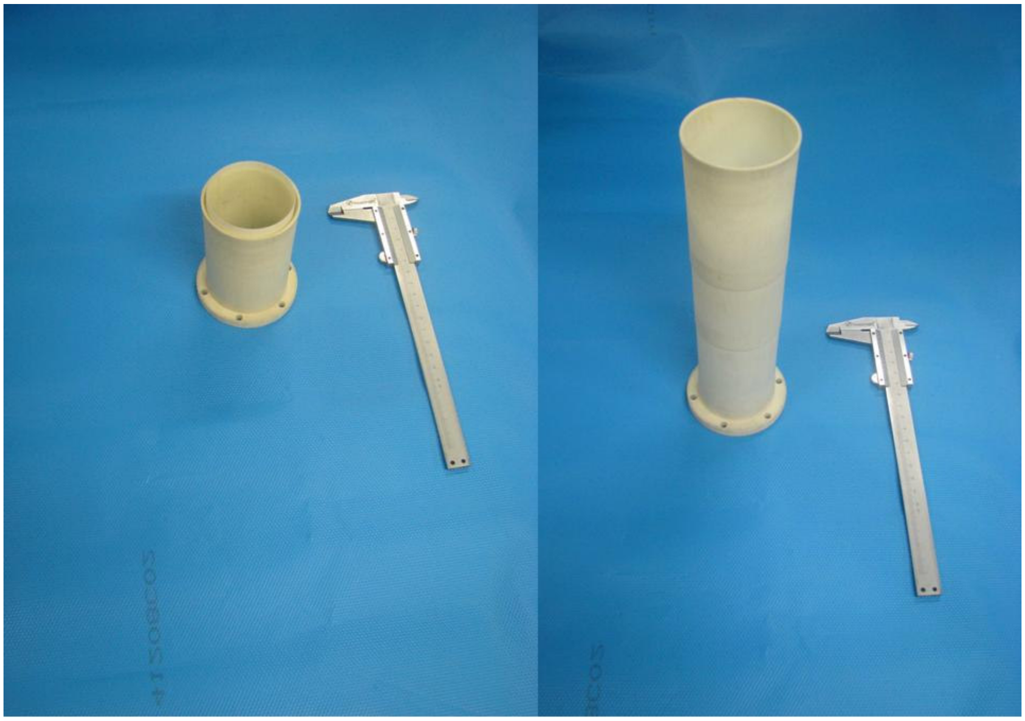
AMS Superfluid Helium Tank Burst Discs



36


AMS Superfluid Helium Tank Burst Discs
Existing BD03
SFHe Tank wall
Existing re-entrant SS tube
VCS 2 Hard Shield
VCS 4 Hard Shield
Tee Adapter (fiberglass)
New BD06 A & B (not shown)
Telescoping Tube (fiberglass)
Existing Thermal Bus Bars
Tee (fiberglass)
SS Flexible Bellows (2)
Bellows Adapter (fiberglass)
37


Telescoping Tube Reinforcement layers and Collar (in red)
The inside diameter of the 3 Telescoping Tubes sections get progressively larger from BD03 to the Tee Adapter
Note that zero thrust vent would still be installed external to the VC
Radiation Shield connected to Thermal Bus Bars
38



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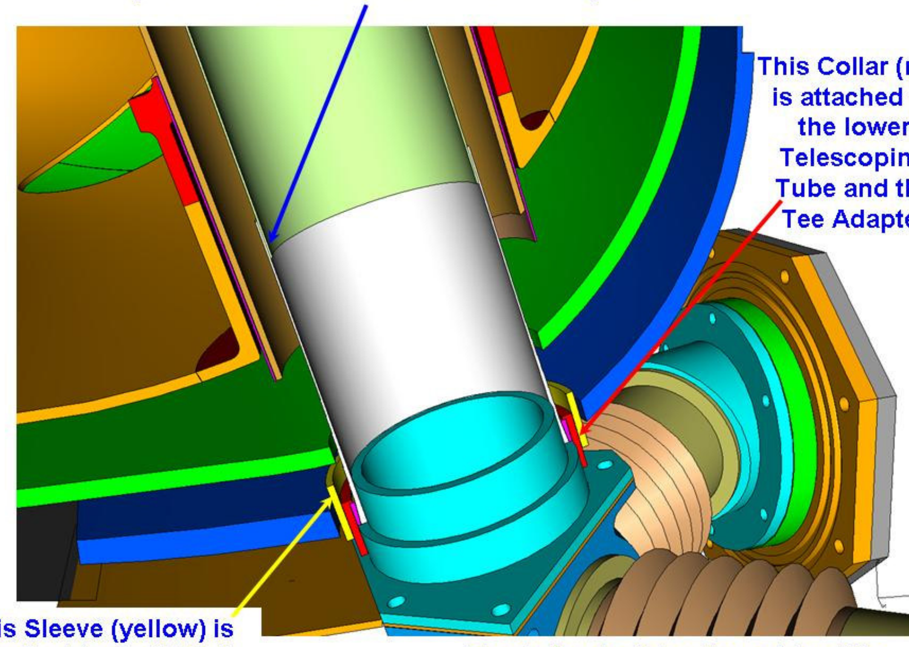

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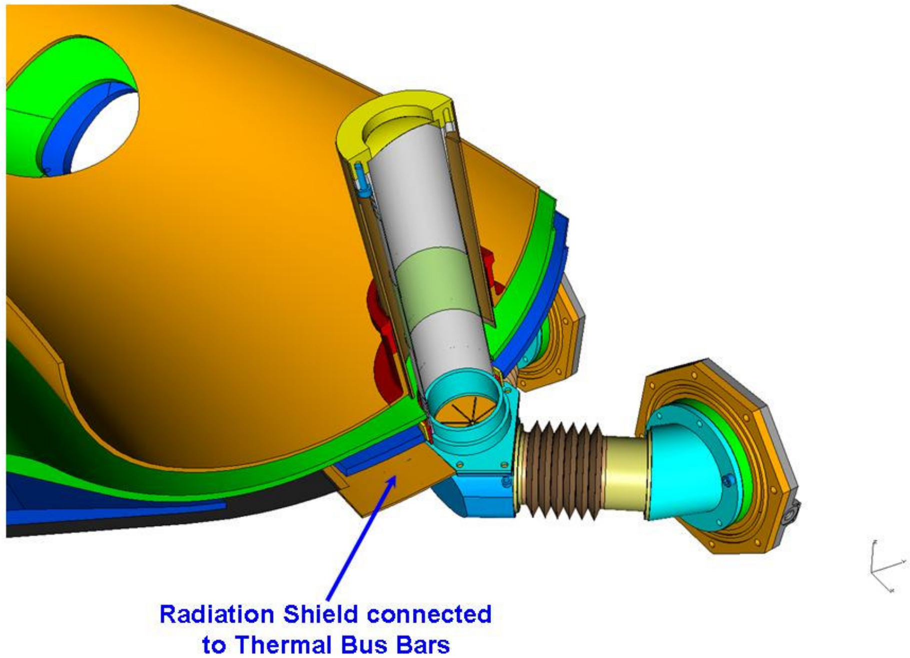
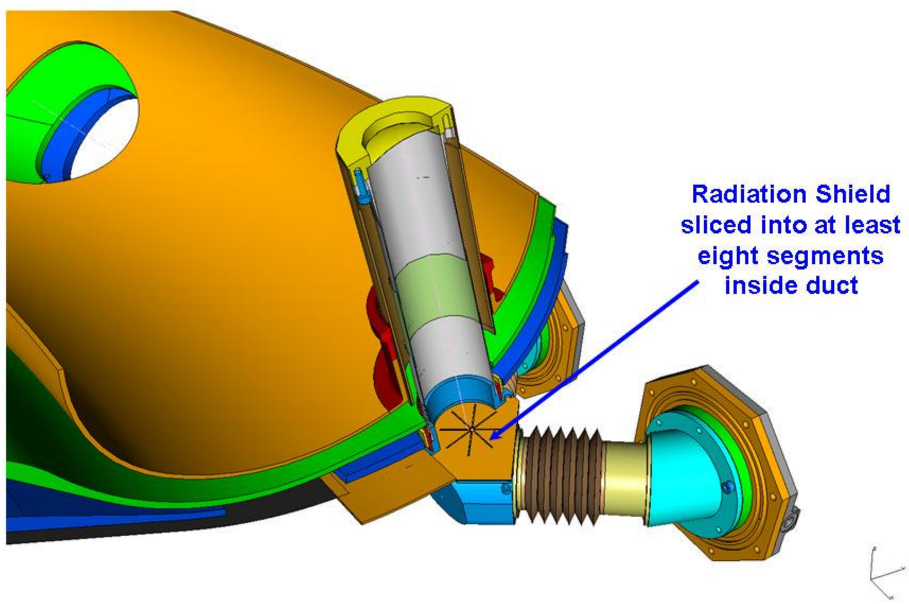
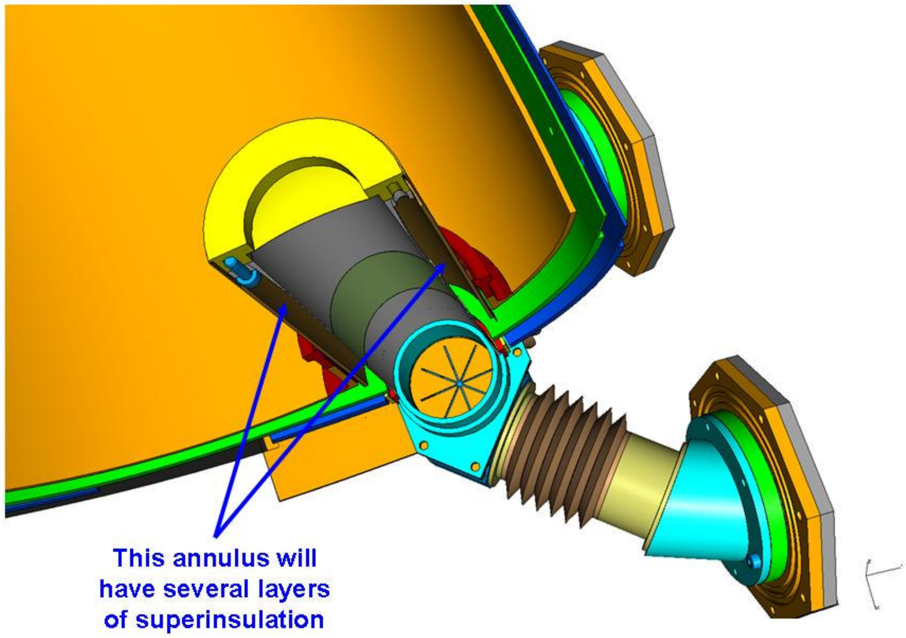

Radiation Shield connected
to Thermal Bus Bars

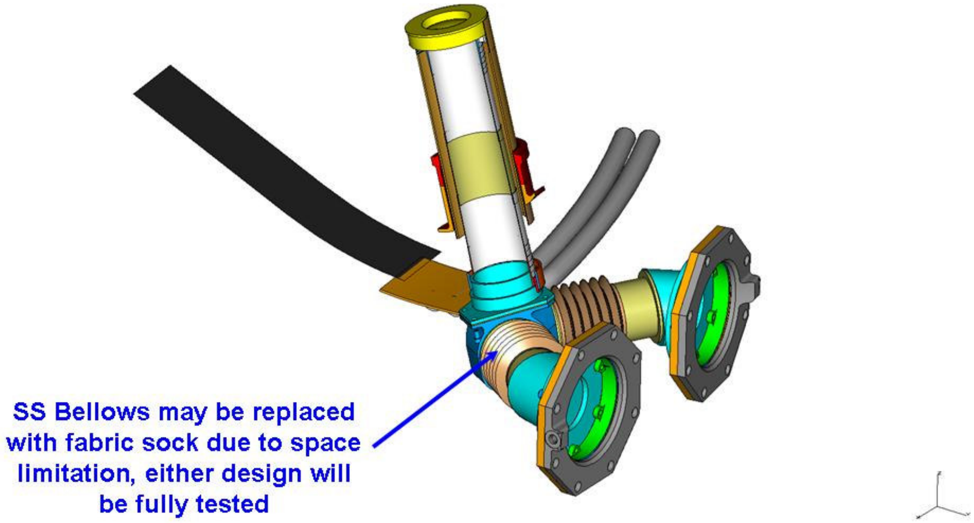
41


Radiation Shield
sliced into at least
eight segments
inside duct

42



43



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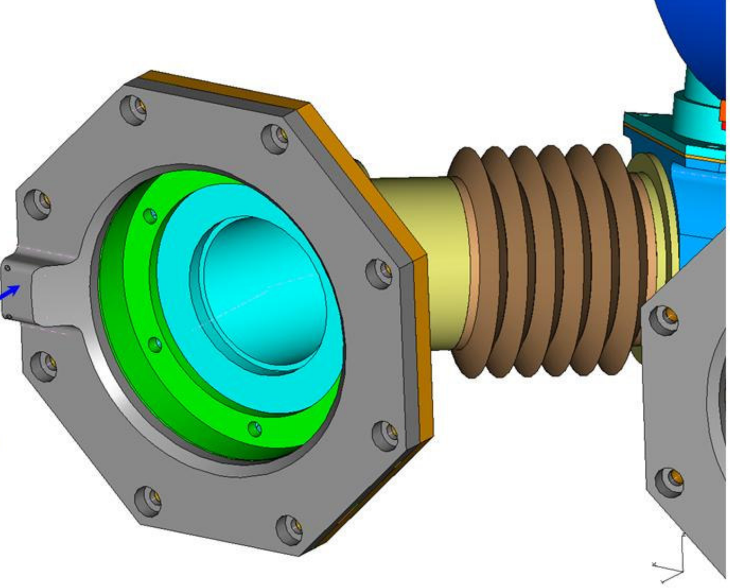

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Proposed New Testing

- At least 8 tests of this new configuration will be conducted
  1. Telescoping Tube Static Test - Rome
     - Purpose of this test is ensure that we have a positive margin of safety with a factor of safety of 2.0. The test has been completed, and the telescoping tube was taken to 11 bard without failure. Because the tube did not fail, we do not yet know the ultimate margin of safety, but we do know that it is well above zero.
  2. Telescoping Tube Cryogenic Static Test - Geneva
     - Similar to test 1, but performed in a nitrogen bath (77K).
  3. Stainless Steel Cryogenic Static test to failure - Geneva
     - Purpose of this test is to understand the margin of safety of the SS bellows. The ends of the bellows will be offset by the worst case expected flight deflection. The expansion of the bellows will be restricted along the central axis, as it will be in the flight configuration, and the bellows will be pressurized to failure in a nitrogen bath.
  4. Room Temperature Test of new Burst Disk Test Rig (BDTR) at Texas A&M
     - A new BDTR is being built at Texas A&M that will allow us to test the entire BD03 to BD06 system in a flight like configuration. In this test, a tank of liquid helium will be pressurized to the burst pressure of BD03 and all of the burst disks will be allowed to burst as they will in the flight system. This first test will be done at ambient temperatures but will include a test disk rated at 2.7 bard to simulate BD03 and two disks rated at 0.76 bard to simulate BD06A and BD06B. A complete set of the telescoping tube, Tee, Tee Adapter, two Stainless Steel bellows, two bellows adapters, and two intermediate flanges. The sleeve for VCS4 will be accurately modeled in the test. The BDTR will be designed such that the outlet for BD06A and BD06B are intentionally offset by the maximum expected flight deflections.

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Proposed New Testing, Cont.

- At least 8 tests of this new configuration will be conducted
  5. Cryogenic test of BDTR at Texas A&M
     - Same as test 4, but performed using liquid helium. This is an all up dress rehearsal for the flight like tests.
  6. Flight Test #1 at Texas A&M
     - This is a cryogenic test with burst disk assembly attached to liquid helium tank. Test will utilized flight BD03 and one flight BD06. The second BD06 port will be blanked off. This will simulate the failure of one of the BD06s to open. The zero thrust T-vent will be installed for the test. Once successful, we will begin welding the flight VC closed and continue flight hardware processing.
  7. Flight Test #2 at Texas A&M
     - This is the most severe and conservative test we will do. This test will be like Flight Test #1, but we will install both BD06A and BD06B. Zero thrust vents will be installed on both BD06A and B. During this test, we will attach the detached BD03 disk membrane from the failed test in July. This will intentionally act as 'shrapnel', so that we can be assured that even if the BD03 disk membrane breaks off on the flight system, the safety system functions properly.
  8. Flight Test #3 at Texas A&M
     - This is our final flight test with BD03 and both BD06A and BD06B installed. Zero thrust vents will be installed on both outlets.

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BD03/06 Telescoping Tube Tests

The tube was then placed in a small styrofoam dewar and connected to a 0-50 bar pressure gauge

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BD03/06 Telescoping Tube Tests

Then the tube was pressurized from ~1 bar to ~36 bar in ~15 seconds. The last part was from ~30 bar to 35 bar in ~2 seconds.

Moments before failure…go Kerry go!

We only need 3 bar, and the test shows that the tube can withstand more than 35 bar.

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BD03/06 Telescoping Tube Tests

The glued interface to the end cap for the test failed while the tube remained intact. When this is bolted to the BD03 flange, it will be a stronger joint.

NASA JSC
Payload Safety Review Panel
Alpha Magnetic Spectrometer-02
Burst Disk
Technical Interchange Meeting

Minutes of Meeting
August 13, 2009

1.0 INTRODUCTION

1.1 **General:** The Payload Safety Review Panel (PSRP), chaired by JSC/OE/M. Surber, met on August 13, 2009, with representatives of the JSC/Alpha Magnetic Spectrometer (AMS) Project Office, the Payload Organization (PO), at the Regents Park III Conference Facility for an AMS-02 Burst Disk Technical Interchange Meeting (TIM). JSC/NA2450/R. Rehm and K. Chavez, the supporting Payload Safety Engineers (PSEs), introduced the meeting and attendees (see Attachment 1).

1.2 **Background:** The PO has coordinated the current design of the AMS-02 Dewar Burst Disks (BDs) through numerous meetings with JSC/Pressure Systems and the PSRP. The PSRP held the following meetings on AMS-02:

- Helium Venting TIM, 4/20/00
- Phase 0/I Flight Safety Review (FSR), 1/16/01
- Vacuum Jacket Leakage Special Topic Meeting, 10/11/01
- Gauss Limit Special Topic Meeting, 10/16/01
- TIM, 1/17/03
- Phase II FSR, 5/21-25/07
- Hazard Report (HR) TIM, 10/10/07
- Non-compliance Report (NCR) TIM, 12/10/08

1.3 **Scope:** This meeting focused on the PO report of BD test results. The PSRP reviewed no previous action items (AIs) associated with this payload in this meeting.

1.4 **Conclusion:** No agreements and no AIs resulted from this meeting. The PSRP reviewed no HRs. The PSRP accepted the PO's proposed resolution and redesign of the BDs for the vent lines. The PSRP urged the PO to have all verification tracking log (VTL) items that are not associated with nominal ground processing for launch closed prior to the Phase III FSR. The PO also should include the assessments of the composite-over-wrapped pressure vessels (COPVs) and the WSTF review (visual inspection) of them in the Phase III Flight Safety Review (FSR).

2.0 SIGNIFICANT SAFETY DISCUSSION

2.1 **Science Overview:** The AMS-02 experiment is a state-of-the-art particle detector that will search for antimatter and dark matter in space and study galactic cosmic rays. The experiment will advance our knowledge of the universe and its origin.

The AMS-02 experiment uses a large cryogenic superfluid helium (SFHe) superconducting magnet (Cryomagnet or Cryomag) at 2°K to produce a strong, uniform magnetic field (~0.8 Tesla). Due to the differences in electrical charge, particles of matter will curve one way when they pass through the magnetic field, and antimatter particles will curve in the opposite direction. The mass of the particles determines the amount of curvature. Planes of detectors above, in the center of, and below the Cryomagnet record the unique particle signatures. The AMS-02 will collect data from the ISS for at least three years.

2.2 **Hardware Overview:** The PO conducted hardware inspections at Geneva, Switzerland, and at KSC. The Shuttle will ferry the AMS-02 experiment to the International Space Station (ISS) for installation on the external truss of the ISS. Due to limited Shuttle flights, AMS-02 will remain on the ISS indefinitely.

2.2.1 BDs: A BD is basically a highly reliable "fuse" for fluid lines. The BD design is single-fault tolerant to prevent leaking atmosphere into the helium system. BD07 protects the Dewar from venting helium into the payload bay.

2.2.2 Kapton Tube: The Kapton tube is used only for installation; it is fixed during operation. The telescoping Kapton tube is designed for thermal expansion and will withstand launch loads. Testing showed that the internal diameter (ID) of the Kapton tube was too small for the BD opening.

2.2.4 Radiation Shield: The PO will test the Radiation Shield.

2.2.5 Flange: The PO clarified that the flange that failed was a test article and not a flight unit.

2.2.6 Bellows or Fabric Sock: The PSRP inquired about the effect of air passing over the folds in the bellows at high velocity and whether this is a concern. The PO indicated that they are considering replacing the stainless steel bellows with a fabric sock for unrelated reasons.

2.3 **Burst Disk Test:** The PO conducted the following tests on the BDs:

- Acceptance testing on individual BDs and on assemblies, if in series
- Vibration testing on assemblies
- Leak testing on individual BDs and on assemblies

The spare BD03 membrane disengaged during the test on July 9, 2009. The failure was that the BD membrane tore loose completely, which had not occurred previously. Failure of the burst disk membrane is believed to have been caused by a design flaw in the fiberglass flange used to attach the Kapton tube to the BD03 assembly. The flange, which was supposed to be at least the same diameter as the BD opening, was actually 6.6 mm smaller in diameter than the disk opening. This caused the membrane to impale itself onto the fiberglass flange, weakening the hinge line and causing the membrane to detach. The Kapton tube failure could have been caused by the disk membrane impact or by the difference in the dynamic burst mechanism. The dynamic impact of this difference could have been enough to rupture the Kapton tube. The BD07 tests reported no leakage.

2.3.1 Anomalies during Testing/Assembly/Ground Processing: The PO found that the pressure dynamic load was much higher than expected, and any new design should attempt to accommodate this finding. This result was unusual because of the low pressure dynamic load that was seen in the testing conducted prior to this failure. Previous testing did not use Burst Disks, due to cost and availability, but rather valve opening.

2.4 **Failure Scenarios:**

2.4.1 BD on Launch: The PO analyzed various scenarios that might require a Trans-Atlantic Abort Landing. The PO said that it will monitor heat sources up to 9 minutes prior to launch (L-9) as a requirement for Launch Commit Criteria. The payload bay overpressurization concern is only credible between L+30 sec. and L+60 sec., not to include a launch abort scenario. The Space Shuttle Program office is aware of this and gave its approval to this assessment.

2.4.2 Variable Specific Impulse Magnetoplasma Rocket (VASIMR) Impacts: Both the AMS-02 and VASIMR payloads use large magnets. The AMS-02 PO reported that it has communicated with the VASIMR project management to determine whether VASIMR's strong magnetic flux could affect the operation and data quality of AMS-02. The PO found no hazards or mission success issues to report. VASIMR magnets are smaller than the AMS-02 Cryomagnet, and they only operate at times other than when AMS-02 will operate. Plasma concerns from VASIMR are still being evaluated to determine if they could affect AMS-02 science.

2.5 **Design Changes Since the Non-compliance Report TIM (12/10/08):**

2.5.1 Resolution: After the test and investigation, the AMS team developed a go-forward plan that will

- Eliminate the Kapton tube, replacing it with a more robust composite telescoping structure.
- Replace the existing internal T-Duct (Cow Horns) with a new T-Duct system that thermally isolates and provides redundant paths to new external BDs.
- Replace the BD06A/B assembly with two larger lower-burst pressure BDs in parallel. The result would be that there should be just one burst disk in each of the three vent lines. Reducing the burst pressure on the external disks should make the design safer and ensure adequate vent area. Since BD07 has already been qualified and meets these criteria, several single BD07 assemblies are on order for testing and final flight configuration. Tests show that the BDs do not leak, but additional testing is needed to demonstrate that, if they do leak, the safety system will still function. The PO plans to add a zero thrust vent to the burst disk in BD07.
- Implement an additional thermal radiation barrier made of one layer of 0.3 mm-thick pure aluminum to help improve the thermal performance of the system.
- Perform a series of tests to show that this new configuration functions properly, even under worst-case safety conditions.

2.5.2 Proposed New Testing: The PO proposed eight tests for the new configuration:

- Telescoping Tube Static Test (Rome)
- Telescoping Tube Cryogenic Static Test (Geneva)
- Stainless Steel Cryogenic Static test to failure (Geneva)
- Room Temperature Test of new Burst Disk Test Rig (BDTR) (Texas A&M University)
- Cryogenic test of BDTR (Texas A&M)
- Flight Test #1 (Texas A&M)
- Flight Test #2 (Texas A&M)
- Flight Test #3 (Texas A&M)

2.5.3 Discussion and PSRP Approval: The PO explained that JSC required it to provide three burst disks for two-fault tolerance to protect the Dewars from the hazard of backflow air leakage that might overpressurize the helium tank and cause it to leak into the payload bay. The PSRP said it believes that the original design was still single-fault tolerant. In fact, the PSRP concluded that multiple discs are actually less reliable than a single BD. In the test configuration, the PO removed one burst disc from the assembly as well as the 90-degree turn in the line that it believes caused the pressure shock that resulted in the burst disk failure. The two-BD testing configuration reduced pressure in the large tank following bursting. The PSRP concurred with the new design, which will include one BD with a single-thrust vent. The PSRP considered the design changes as meeting requirements for "failsafe."

2.5.4 Panel Poll: The PSRP polled its members to determine whether the solution to the BD anomaly is acceptable. The panel members replied as follows:

- Shuttle Integration—Acceptable, with high confidence based on extensive previous analysis.
- Mission Operations Directorate (MOD)—Acceptable, with no issues.
- Crew Office—Acceptable.
- PSEs—Acceptable.
- Executive Officer (XO)—Acceptable.
- Chair—Acceptable.
- Engineering—Acceptable.
- Extravehicular Activity (EVA)—Acceptable.
- Payload Engineering & Integration (PE&I)—Acceptable.
- Pressure Systems—Acceptable; the test failure was fail-safe.
- Mechanical Systems Working Group (MSWG)—Acceptable.

2.6 **Safety Assessment:**

2.6.1 Form 1428, Fire Detection and Suppression Reporting Form: *Not applicable to this hardware.*

2.6.2 Form 622, Reflown and Series Payload Hardware Reflight Assessment Reporting Sheet: *Not applicable to this hardware.*

2.6.3 Form 1114A, Certificate of Payload Safety Compliance: *Not discussed in the meeting.*

2.7 **Hazard Report Discussion:** *Not discussed in the meeting.*

3.0 **AGREEMENTS:** The PSRP made no agreements with the PO in this meeting.

Original signed by:
JSC/NA2450/R. Rehm
Payload Safety Engineer

Original signed by:
JSC/NA2450/A. Coleman
Technical Writer

Original signed by:
JSC/NA2450/K. Chavez
Payload Safety Engineer

Status of Hazard Reports Presented

The PSRP reviewed no HRs in this meeting.

Previous Action Item Status

The PSRP reviewed/assigned no previous AIs associated with this payload in this meeting.

ATTACHMENT 1

Payload Safety Review Attendance Log

Payload: AMS-02 Burst Disk TIM

Meeting Date: August 13, 2009

Mail Code	Name	Phone 281	X
CHAIRMAN			
OE	Surber, M.	483-4626	X
SUPPORT PERSONNEL			
CB	Rickard, J.	483-3760	X
DA8/USA	Knutson, D.	483-4405	X
EA441	Henning, G.N.	483-0533	X
MO2	Kunkel, S.	483-4356	X
NE14	Guidry, R.	244-5510	X
SM	Spann, R.	483-3807	X
NT	Nobles, D.	335-2129	X
EP4/Jacobs	Manha, W.	483-6439	X
ESCG/JACOBS	Ross, S.	461-5710	X
ESCG/JACOBS	Brown, G. A.	461-5435	X
Boeing/HB3-40	Miley, R. R.	226-4968	X
NA2450/GHG	Chavez, K.	335-2374	X
NA2450/GHG	Mensingh, P.	335-2363	X
NA2450/GHG	Rehm, R.	335-2364	X
NA2450/JES	Coleman, A.P.	335-2391	X
NA2450/JES	Stauffer, P. W.	335-2402	X

Name	Mail Code	Employer	Phone Number	Technical Discipline	Internet Address
Harvey, E. K.		Barrios/ ESCG	281-461-5509 JEI SA	Systems Safety Engineer	eric.harvey@escg.jacobs.com
Martin, T.	EA	NASA	281-483-3296	AMS Project Manager	trent.d.martin@nasa.gov
Hill, L.	4E	ESCG/ Bastion	281-461-5701	Safety	leland.hill@escg.jacobs.com
Tutt, C.		ESCG	281-461-5703	Project Management	john.tutt@escg.jacobs.com
Mott, P.		ESCG	281-461-5712	AMS Chief Engineer	phillip.mott@escg.jacobs.com

11. AMS-02-A11 – Fire in AMS-02 Battery Box During Ground Testing

Description of Event:
During testing, November 2006, of the AMS-02 Uninterruptible Power Supply (UPS) Engineering Development Unit at CSIST (Chung-shan Institute of Science and Technology) the battery assembly experienced a thermal runaway that resulted in a aggressive fire event that destroyed the UPS assembly.

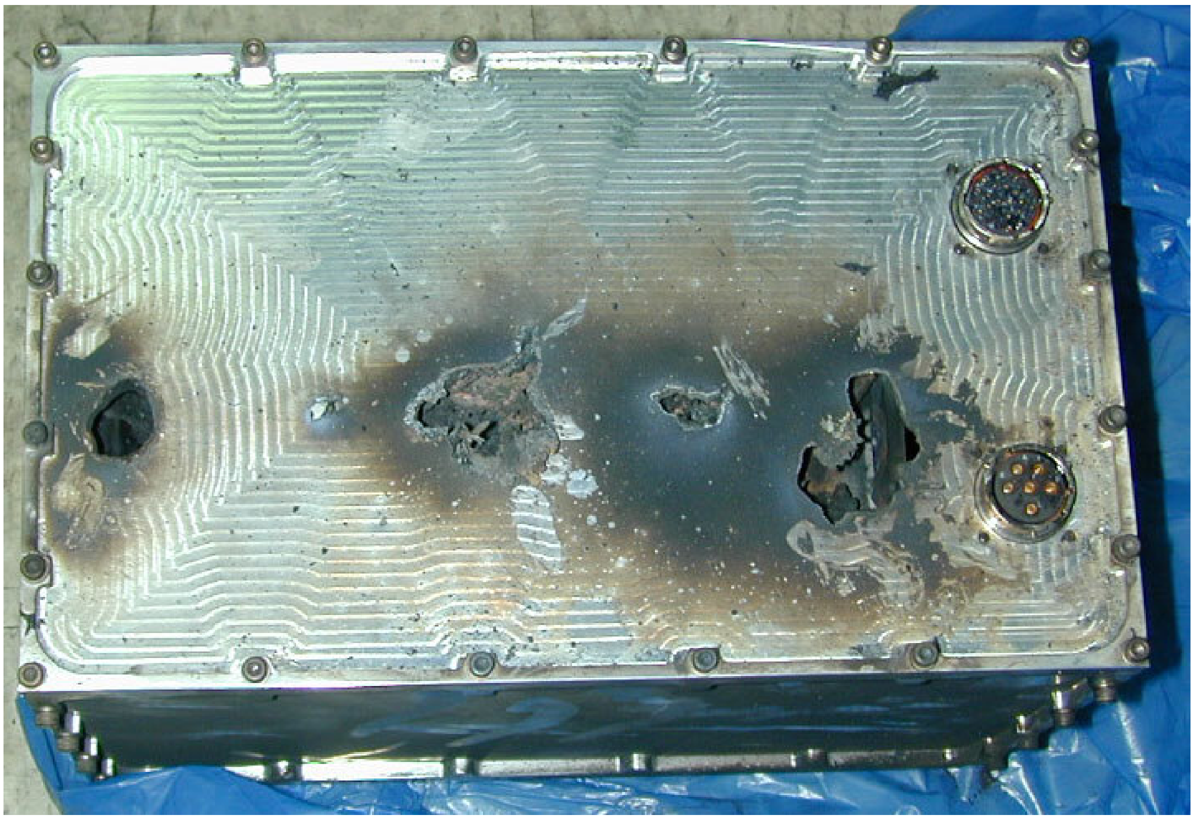


Figure 11.1 – Engineering Development Unit (EDU) UPS after fire event.

Corrective Action: Upon review of the SYSU test set up and procedures, it was established that the charging system had not implemented the required controls to limit current or monitor battery performance that would have been enacted to compensate for the cell failure observed. Also at the time of the testing event, the testing engineers were absent. All remaining UPS units were returned to Yardney, the manufacturer of the cells and testing resumed at that location. See AMS-02-A12 for performance issues with remaining UPSs.

Safety Impact: Significant. The fire in a battery system that was designed to preclude such an event was taken as a significant safety event. It was not until it was established that the testing set up and process was not implemented in such a way to make use of the design features and the established protection protocols, that the battery design was eliminated as a cause of the fire. While the cell partial short was an anomaly in the cell, the BMS design within the UPS will detect and isolate this problem. The test configuration could not.

Status: Closed. Testing resumed in a new laboratory. See AMS-02-A12.

SUPPORTING DOCUMENTATION: (follows)

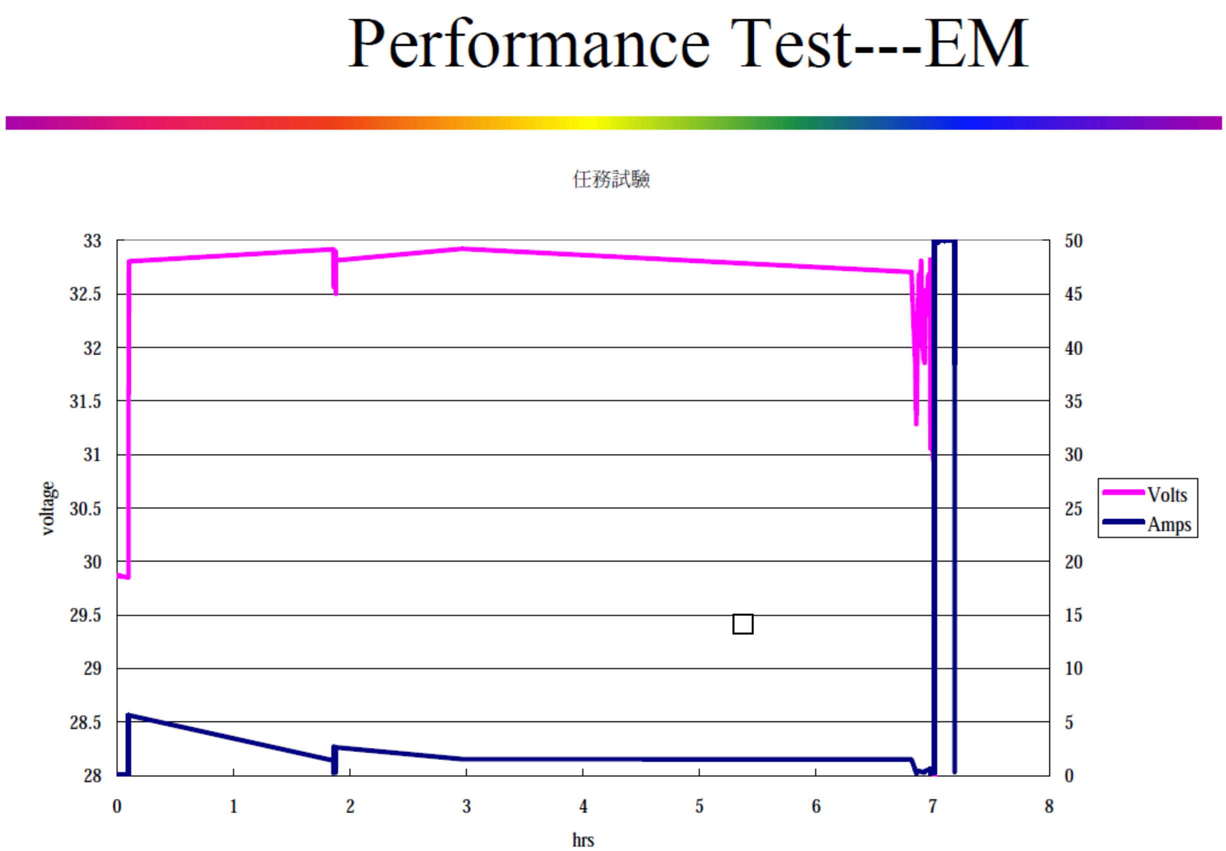


Figure 11-2 Performance Testing of UPS.

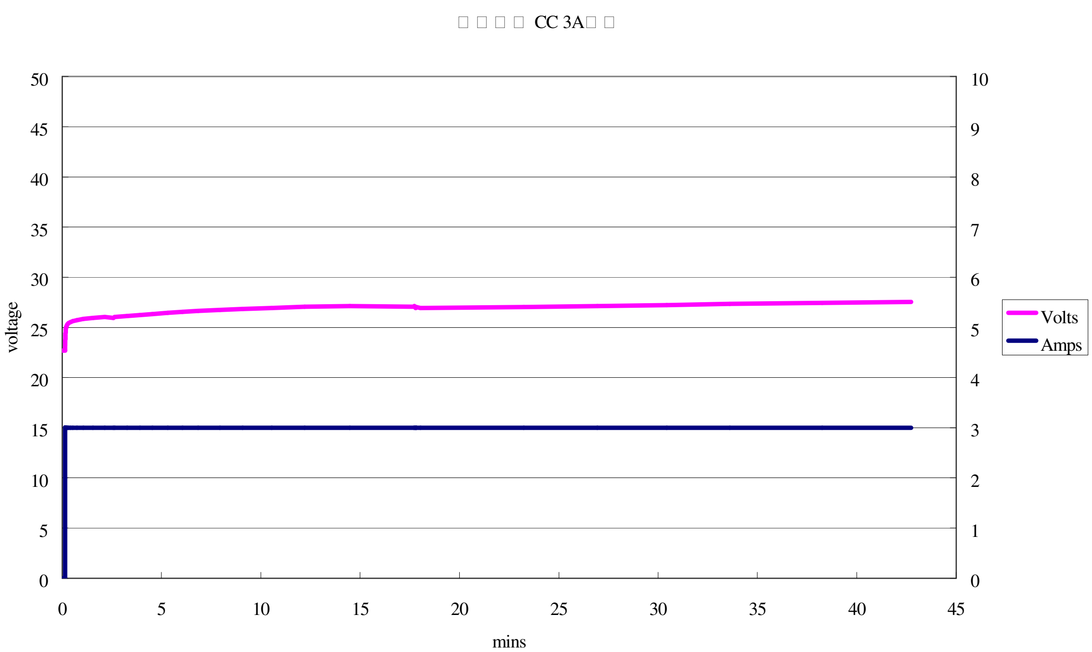
Notes of event:

EM UPS Testing

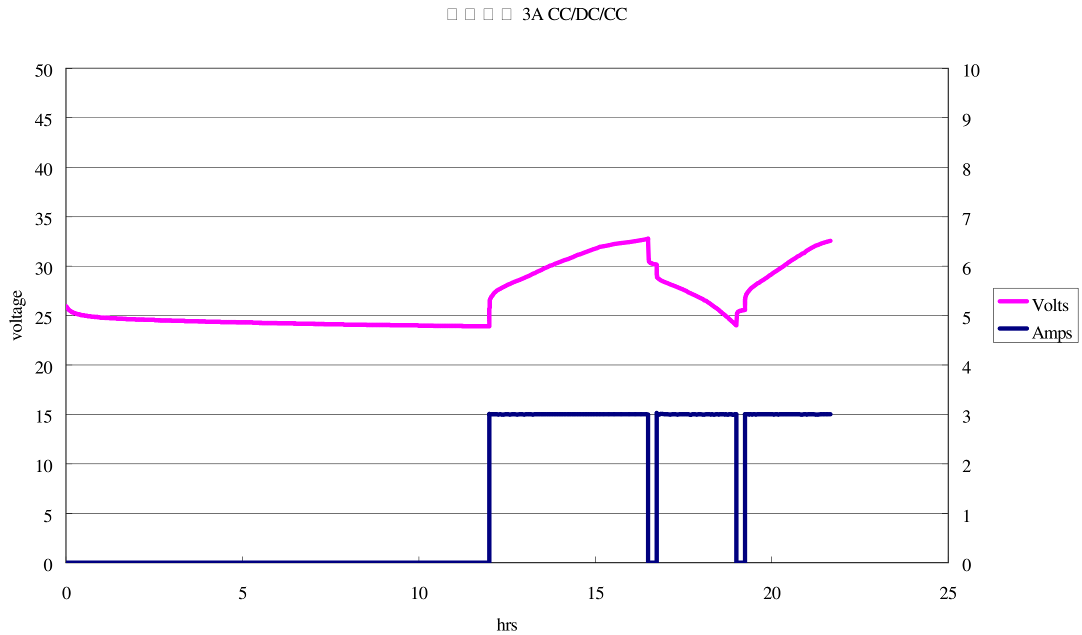
1. EM UPS was charged at 3 Amp constant current with Maccor S4000 Battery Tester for 43 minutes (Graph 1). After 12 hours Open Circuit, EM was charge/discharge/charge one cycle at 3 Amps (Graph 2). Battery Capacity is about 3 Amps x 3 hour=9 Amp-hrs.
2. EM was charged at 5.6 Amps for only 1.3 minutes (Graph 3) and stopped for take movie of EM UPS Testing.
3. EM was charged at 5.6 Amps for about 0.3 minutes then EM was charged at constant voltage for about 7 hours (Graph 4). We try to execute 4.1 Performance Test.
4. EM Battery had encountered partial short at about 1.9 hours (about 0.4 volts drift) and 6.9 hours (about 2 volts drift). After that battery voltage had been dropped to zero volts and the charge current had been

increased to 50 Amps to compensate the voltage setting of 32.8V during constant voltage charge. The maximum charging current of Maccor S4000 Battery Tester is 50 Amps.

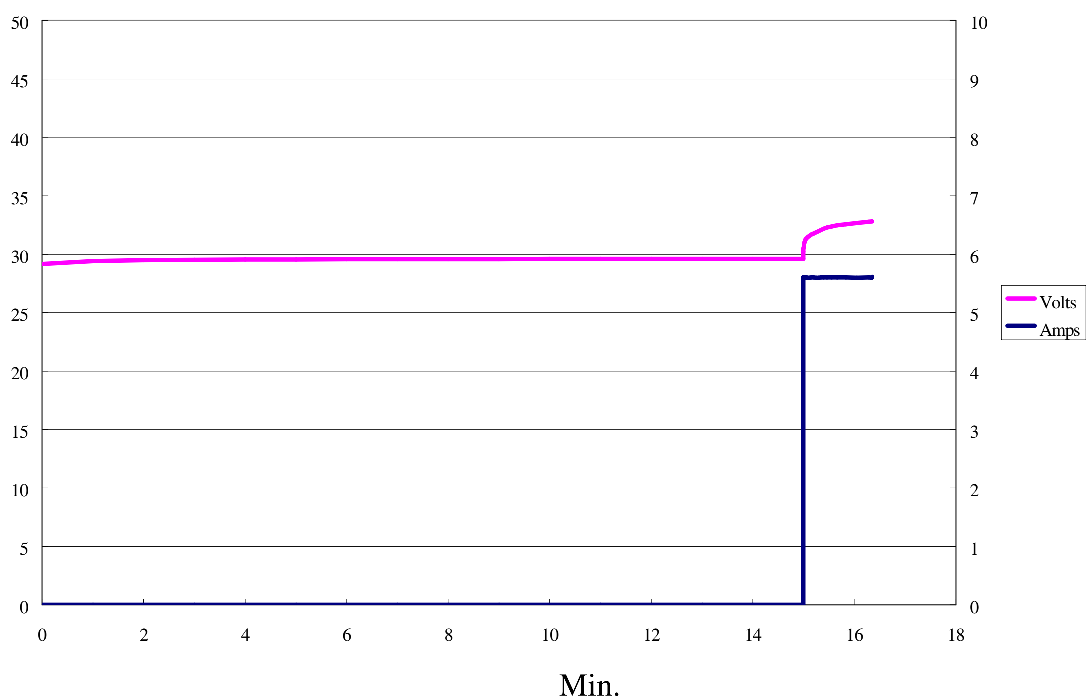
5. BMS charge enable signal was not implemented as an operational control. The charge enable signal from the BMS can not be used as an inhibitor or a disable for the External protection box we try to bought.
6. Parts of the top cover of UPS BOX had been melted due to high temperature (1759.0 deg. C) generated by battery short. J1 / J2 and two Test Connectors are all damaged. The equipment involved in this UPS EM charge failure event has not been tested or serviced following the event.



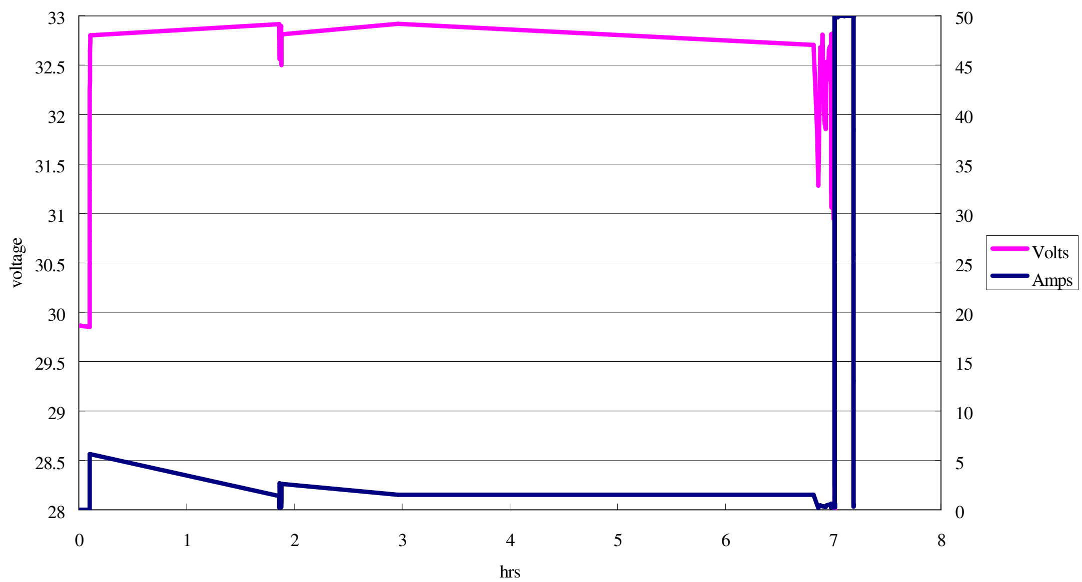
Graph 1: EDU was charged at 3 Amps for about 43 minutes.



Graph 2: Open circuit for 12 hours then EM was charge/discharge/charge at 3 Amps.

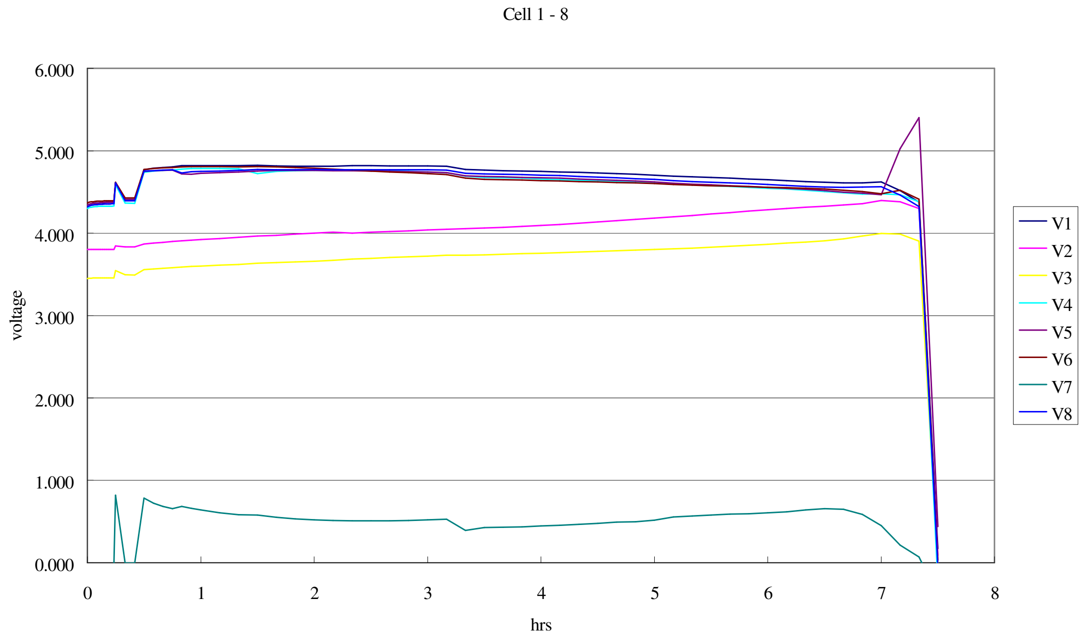


Graph 3: EM was charged at 5.6 Amps for about 1.3 minutes.



Graph 4: EM was charged at 5.6 Amps for about 0.3 minutes then EM was charged at constant voltage for about 7 hours.

7. Unfortunately, only individual cell data of Graph 4 (attached) was taken by Digital Recorder (Accuracy is ±0.01% of reading) due to restriction of the Recorder memory. Voltages of Cell 1 to Cell 8 are cited in Graph 5. At 15:53:02, voltage of Cell # 7 is -0.136 V and voltages of Cell # 2/#3 are3.801/3.450 V. The battery was not well balanced after 1st charge/discharge/charge cycle. Voltage of Cell # 7 was below 1 volt during the Constant Voltage charging period. Voltages of the health Cells #1/4/5/6/8 are above 4.67 V at 16:41:04.
8. At 23:22:58 Voltage of Cell #5 was 5.011 V. At 23:27:14 Voltage of Cell #5 was 5.850 V.
9. At 23:35:28, V5 dropped from 5.521 to -0.077 V; V3 dropped from 3.899 to 0.479 V; V7 dropped from 0.067 to-1.070 V.
10. At 23:43:08 all cells went to zero or negative volts and the temperature at cell #5 was 1759.0 deg. C.


Cell 1 - 8
6.000
5.000
4.000
3.000
2.000
1.000
0.000
voltage
0
1
2
3
4
5
6
7
8
hrs
V1
V2
V3
V4
V5
V6
V7
V8

Graph 5: Voltage of Cell 1 to Cell 8

Time	V	V1	V2	V3	V4	V5	V6	V7	V8	T4
15:53:02	29.02	4.342	3.801	3.450	4.300	4.340	4.367	-0.136	4.318	23.5
16:41:04	32.15	4.706	3.875	3.574	4.675	4.681	4.679	1.006	4.681	25.9
23:27:14	31.95	4.436	4.328	3.947	4.397	5.850	4.326	0.087	4.387	28.5
23:35:26	30.34	4.353	4.285	3.889	4.390	5.521	4.786	0.067	4.301	27.6
23:35:28	27.77	3.716	3.130	0.479	4.466	-0.077	4.806	-1.070	4.040	28.3
23:35:30	-0.83	-3.432	-0.830	-0.518	0.596	########	-1.660	-1.550	-0.674	50.4
23:43:08	0.26	0.136	0.098	0.013	-0.261	0.435	0.029	-0.353	-0.047	1759.0

12. AMS-02-A12 – UPS Battery Cell Undervoltage

Description of Event: During UPS level testing at Yardney, the battery cell manufacturer, it was discovered that some cells in all 4 UPSs exhibited low charge voltages and higher than normal discharge rates. This was seen after the UPSs had been returned from Taiwan (SYSU) due to other testing process related issues (See AMS-02-A11). It is assumed that the cells suffered damage due to improper handling and storage while in the care of SYSU.

Corrective Action: The UPSs were tested and the cells within were attempted to be recovered through conditioning, successfully recovering the performance specifications of some cells. However there were sufficient "bad" and weak cells that it was decided that the UPS compliment of cells needed to be reorganized. The UPSs were disassembled at Yardney and from all of the remaining "good" cells the cell manufacturer assembled two units for further use at CERN during integration and testing. It was decided that, since there were not enough "good" cells to populate a set of flight spares, Yardney would remanufacture sufficient new cells to populate 4 UPSs (2 Flight, 2 Flight Spare). These cells were to be identical to the existing cells and undergo limited testing, including PHYSICAL AND ELECTROCHEMICAL CHARACTERISTICS, FLIGHT SCREENING OF CELLS, TVT .and Vibe Testing.

Safety Impact: None. The original UPSs were tested and shown to have sufficient power with a small margin to accomplish the Watch Dog Timer function that they are provided for, to power a controlled ramp down of the AMS-02 Cryomagnet's power in the even that power or communications are lost from the ISS for a period in excess of 8 hours. As the true source of the diminished cells was not established, it was unsure how the performance over time would be for the UPSs with the "bad" cells. So new cells with full performance compliance were desired so that the original design's margin was restored.

Status: Closed. Cell testing is complete and the Flight and Spare UPSs are under construction.

SUPPORTING DOCUMENTATION: (follows)

13. AMS-02-A13 – Excessive Helium Consumption in Pilot Valves to Cold Weka Valves

Description of Event: During initial cryogenic testing of the AMS Cryosystem and Magnet at CERN, the original Hoerbinger pilot valves installed to actuate the AMS cold and warm Weka valves were found to use excessive amounts of helium.

Corrective Action: A market search was conducted and Clippard valves were chosen to replace the Hoerbinger valves. Pressure, leak, thermal, EMI, vibration, and magnetic field testing was conducted to assure the new valves were suitable. A new Pilot Valve Vacuum Vessel (PVVV) housing the new Clippard valves was developed. A new electrical interface to the Cryomagnet Avionics Box (CAB), modified electrical harnesses, piping manifolds, and brackets for connecting and mounting the pilot valves were also developed. These components all meet the same design requirements as the originals.

Safety Impact: None, this only had a potential impact on mission success based on rate of warm helium consumption.

Status: Closed

SUPPORTING DOCUMENTATION: (follows)

14. AMS-02-A14 – Unreliable Cryosystem Pressure Sensors

Description of Event: During initial cryogenic testing of the Cryosystem and magnet at CERN, the temperature and pressure readings were found to be inconsistent. Research indicated that the leads of the pressure sensors were significantly effected by the temperature, creating variences in the resistance of the lead wires so that depending on the temperature of the sensor, there was an offset imposed.

Corrective Action: It was established that the temperatures sensors were far more effective than low pressure sensors for determining the health and pressure of the Superfluid helium dewar. Nominally the pressure of the tank is at or near vacuum, so pressure variances are small and temperature was more accurate, even as pressure elevated.

Safety Impact: Minimal, pressure sensors are not used to monitor the trends of the Cryosystem, multiple temperature exclusively is used.

Status: Closed.

SUPPORTING DOCUMENTATION: (follows)
None

15. AMS-02-A15 – DDRS-02 Error during EMI Testing

Description of Event: DDRS-02 USB RS422 Assembly malfunctioned and was non functional during the 180.8 – 192.0 MHz section of the RS103 radiated electrical field testing in JSC Building 14 EMI chamber. The purpose of the test was to establish if a susceptibility in the DDRS-02 hardware would propagate and damage the GFE A31p laptop. After the exposure the USB RS422 was properly recognized and functioning, having recovered all function. There was no threat at any time to the GFE hardware.

Corrective Action: Deviation was made to test setup to re-perform a portion of the RS testing in which the EUT was susceptible. In original test configuration, EUT was not fully concealed (not grounded, acted as aerials). Connections TXD, RXD, TXC and RXC were left open and created a path for radiated electric field to enter enclosure. In deviation configuration, loopback cables were connected from TXD to RXD and TXC to RXC. Under retest the DDRS-02 USN RS422 Assembly passed the previously failed range.

Safety Impact: None

Status: Closed

SUPPORTING DOCUMENTATION: (follows)
None – EMI testing report on file.

16. AMS-02-A16 – Leakage of Explosively Bonded Bimetallic Joint in Cryosystem

Description of Event: The AMS-02 Main Helium Tank has four plumbing feedthroughs which contain an explosively-bonded bimetallic joint to connect the steel plumbing lines with the aluminum tank. These joints were all tested as individual units and found to be leak-tight. After the units were welded into the helium tank, two of the four units were found to have developed leaks during integrated tank testing at Hans Bieri Engineering. The most likely cause of the new leaks was overheating of the bimetallic joint during welding operations.

Corrective Action: The two leaking units were removed and two replacement units fabricated and retested. The welding procedure was revised to include additional levels of thermal protection to limit the heat rise at the joint itself. After installation, both replacement units were retested and found to be leak tight.

Safety Impact: Leakage into the interior of the Vacuum case would have been detected long before AMS-02 integration would have progressed on the ground, there is no safety impact with the corrective action in place.

Status: Closed.

SUPPORTING DOCUMENTATION: (follows)

Figure A16-1 Replaced Bimetallic Joint in Place.

17. AMS-02-A17 – Warm Helium Gas Supply Regulator Divergence

Description of Event: During operations at CERN, the Warm Helium Gas Supply pressure regulator was found to diverge from it's nominal setting of 6 bar to a consistent 6.9 bar.

Corrective Action: The nominal operating pressure of the system has increased slightly, but the MDP (8 bar) of the Warm Helium Gas Supply low pressure side (regulated by the anomalous device) is actually set by pressure relief valves set to open at 7.5 bar (8 bar full flow). The consistency of the regulator in operations has shown that while the value is an excursion, it does not impact the operation or the safety of the Warm Helium Gas Supply.

Safety Impact: None- MDP remains consistent and the operating pressure increases slightly.

Status: Closed.

SUPPORTING DOCUMENTATION: (follows)

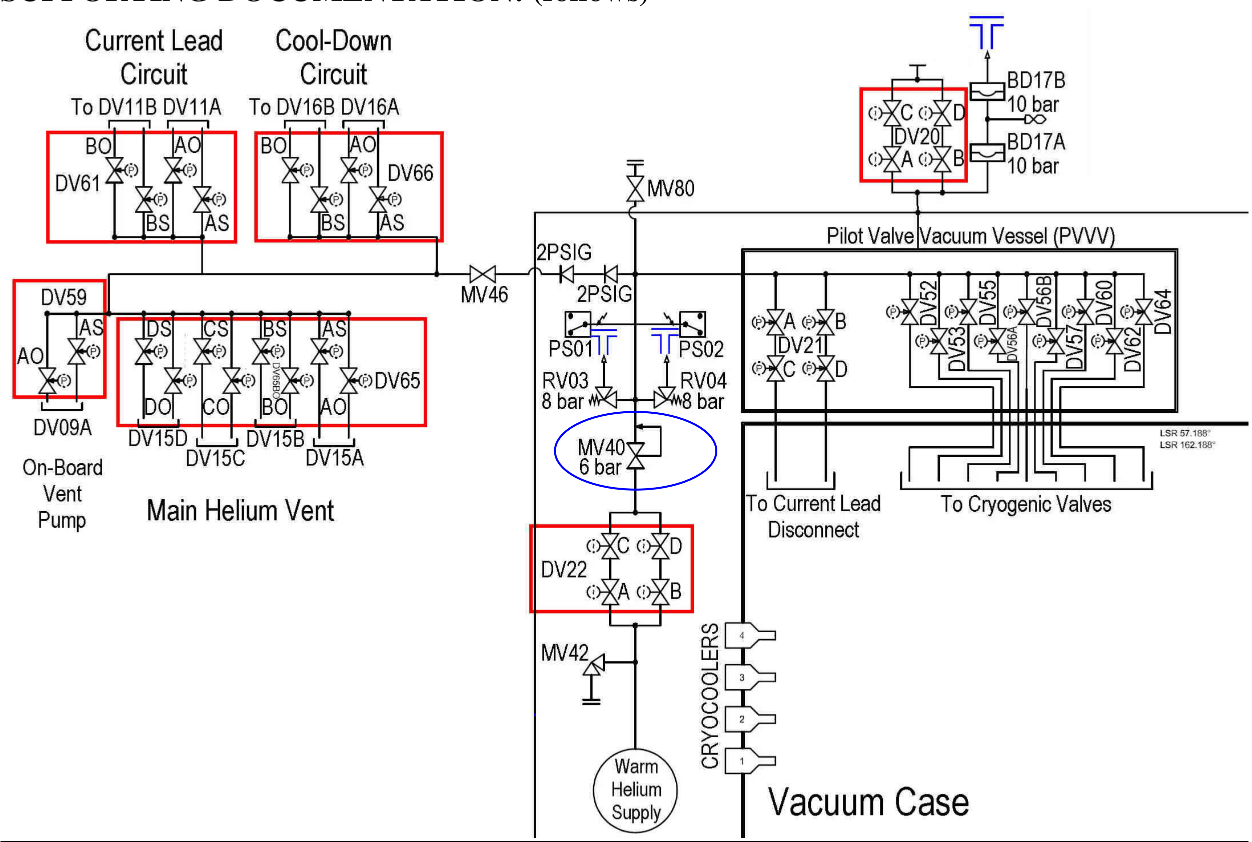


Figure A17-1 Warm Helium Gas Supply (Blue Circle indicates anomalous regulator)

18. AMS-02-A18 – Bubbles in Radiator Heaters

Description of Event: Post-installation inspection of heaters mounted on the back of the Main and Tracker Radiators revealed several small bubbles. Though few and small, these bubbles could possibly lead to localized debonding and overheating of the Kapton foil heaters and eventually heater failure.

Corrective Action: All Kapton foil heaters on the Main and Tracker Radiators were covered with an aluminum tape, which will spread the heat evenly and eliminate any localized hot spots on the heater. In addition, the tape provides additional attachment to the radiator, reducing risk of total debonding.

Safety Impact: Minimal - Bubbles in Kapton foil heaters could have caused localized debonding, localized hot spots, and eventual heater failure. Corrective action was implemented to eliminate these concerns.

Status:

SUPPORTING DOCUMENTATION: (follows)

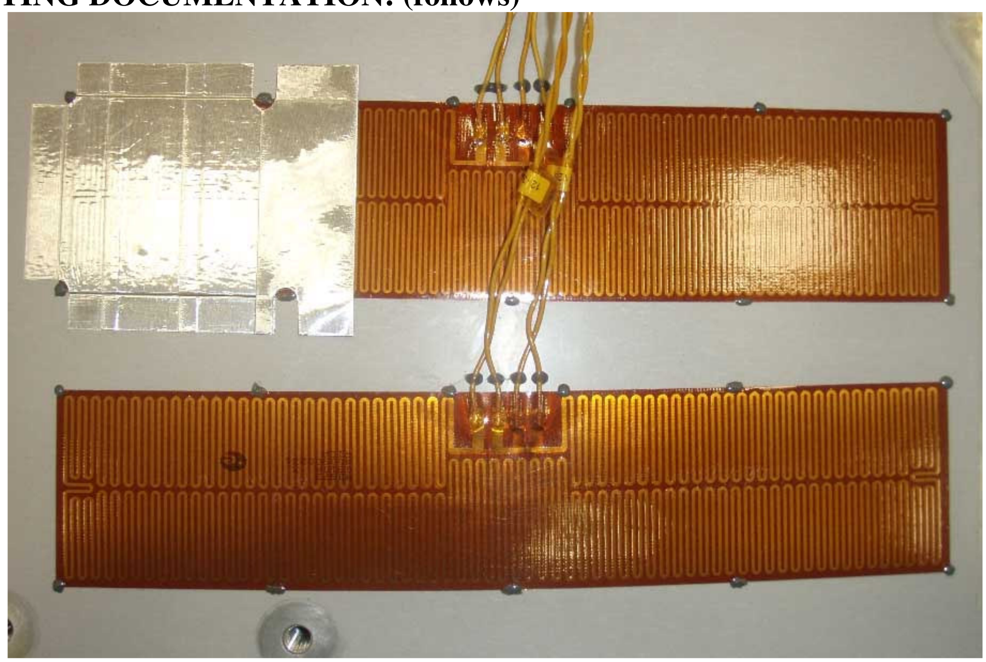


Figure A18-1 Example of covering heater with Kapton Foil Tape (Process incomplete for photo.)

19. AMS-02-A19 – Cleanliness of inside of the Superfluid Helium Tank

Description of Event: During the final cleaning of the Superfluid Helium Tank, higher than expected particulate count was found inside the tank. Although the plan was to clean out the inside of the tank only a few times using clean isopropyl alcohol, the cleaning process took 40 flushes

Corrective Action: Flush the tank with isopropyl alcohol until the particulate count was within the specification. Review this process and results with outside experts, Lou Salerno and Peter Kittel, from NASA Ames Research Center.

Safety Impact: None

Status: Closed

SUPPORTING DOCUMENTATION: (follows)

Memorandum

SCIENTIFIC MAGNETICS

To:	Conference Call Participants	**From:**	Robin Stafford Allen
Ref No.:	Issue 2	**Date:**	12th June 2007
Re:	Cleaning of helium vessel	**CC:**	Stephen Harrison, Trent Martin, Ken Bollweg, Chris Tutt

The helium vessel for the AMS program has to be sufficiently clean for reliable operation of the valves and porous plug. The discussion to date has been as to whether the specification set for cryogenic system components is adequate when the large volume (2500 litres) of the helium vessel is considered.

Cleaning has been underway over some weeks. The cleaning initially was done using washes of 50 – 70 litres of filtered IPA fluid at a time. This wetted the outer skin well and rinsed much of the vessel as the vessel was rotated around its axis, and at the same time perpendicularly to this axis. There is clear audible splashing and sloshing due to this process and the many pockets in the central ring may have carried IPA up into the upper parts of the vessel before allowing it to drain down over the inner skin but it was felt that this might not have washed the entire inner surface of the vessel. To make sure of rigorous cleaning it was agreed that some washes with larger volumes would be undertaken. These have been performed.

The fill required to touch the inner skin with the axis horizontal is around 400 litres. The vessel support jig was given extra support and loaded with 450 litres of IPA and confirmation that the inner skin was around 50 mm into the fluid was made.

The vessel was then rotated around its horizontal axis, as the axle was supported at both ends on stands. The through-tubes could clearly be heard causing turbulence and significant splashing of the IPA. This 450 Litre process has now been completed seven times to date.

The process of loading the fluid and unloading has been established and the results over the first 14 washes showed a significant reduction in the particle count. The assessment process was taken over during the usual engineer's absence and the results between wash 14 and 32 have been discarded as unreliable. From wash 32 onwards the results are felt to be representative. Several changes to the process have been made to ensure that the environmental contamination of the samples is reduced. The sample is taken at a suitable point during the emptying of the fluid, usually at about half-way empty, and the sample is immediately sealed into container and transferred into the lamina flow clean-room area. The air drawn back into the vessel as the fluid is removed is now also filtered.

The fluid sample is passed through a 47mm diameter, 0.45 micron, 'grid' filter paper and the paper examined under a microscope. Initially 100 mls. of fluid was filtered and examined and 5 squares of the paper counted (of the 100 squares of the full area of the filter paper). With the large number of particle this was a very time consuming process. The sample results were multiplied by a factor of 20 to give a comparison with the Cleaning Specification. As the number of particles has dropped the amount of fluid has

now been increased to 250 mls. and the number of squares counted increased to 10. The results are then only multiplied by factor of 4 to compare with specification (100mls, 100 squares).
The results are tabulated below and show the number of particles in the cleaning fluid normalised to the 100 mls of the Cleaning Specification. They show a reduction over the 40 IPA cleaning cycles so far.
To make a summary chart a weighted system has been used. This turns a particle size and frequency spectrum into a single number for comparison. It was felt that the smallest particles were the most concerning and so the weighting was defined as follows

Larger than 100 micron	x1
Less than 100 micron	x2
Less than 50 micron	x4
Less than 25 micron	x8
Less than 10 micron	x16

The weighted total is then divided by 31.
Employing this weighting calculation, the AMS particle Specification level comes out at 27. The chart on the last page shows the examination of the repetitive washes of the vessel and the improvements in the cleanliness can be seen.
The comparison dark blue bars on the bar chart are at the Cleaning Specification value of 27 units. The recent samples are around or below this level in this weighted system. No clear and significant change, only a slight transient rise, in the particle evaluation occurred when switching from 70 litres to 450 litre washes.
Control samples are examined. The control samples are samples of the fluid as it is pumped through the filters into the vessel. The results have been helpful in improving the process of reducing contamination, and the control samples are showing very similar profile of particles to the fluid now coming out of the vessel.
Mark Gallilee has now had an opportunity to examine the last two filter papers. He had performed all the examinations up #33 but he was unavailable for the last washes. His examination produces slightly higher particle count, but this may be due to sampling different 10 squares on the paper, which were chosen at random, or the fact that the filter paper had been stored in a plastic zip-lock bag for some days before being re-examined, which gave the opportunity for a low level of contamination. In any event the levels of contamination found were of the same order as the first examination. His figures have been added to the tables.

End-of-rinse fluid assessment.

Toward the end of the fluid pump-out, the last 30 – 50 litres is again washed around the vessel and as quickly as is practical allowed to flow out of the vessel into a catch-pot. The debris that settles in this catch-pot is observed rather subjectively. This has reduced from a significant quantity per Ken's original photographs to a few dozen particles. The amount it probably one or two orders of magnitude less in quantity than in the early washes. This has been consistent with the dropping in the particle count of the fluid samples.
The vessel cleaning has been developed as it has progressed. However with the equipment and the environment in which the cleaning is progressing, we appear to be almost at the limit of what can be achieved. A decision is required as to whether the vessel needs to be any cleaner for functional purposes.

Porous Plug Assessment
The porous plug has a diameter of 20 mm, so an area of 314 mm^2.
At the Cleaning Specification level of 39 particles of 10 micron diameter per 100 mls, throughout a volume of 2,500 litres, and assuming all particles are 10 micron by 10 micron (0.01 x 0.01 mm) the area covered by all these particles would be 97.5 mm^2.
This is approximately one third of the porous plug area in this worse-case analysis.
The charts are attached.

RCSA.

Specification per 100 mls of wash	39	15	3	1	0	
Specification per 1000 mls of wash	390	150	30	10	3	1
	1	2	3	4	5	
Sample item	5-10micron	11-25micron	26-50micron	51-100micron	>100micron	>200 micron
sample 4	780	440	240	80	120	
sample 5	500	280	140	20	160	
sample 6	480	120	260	40	100	
sample 7	260	220	140	20	120	
sample 8	140	100	40	100	80	
sample 9	280	60	60	20	180	
Sample 10	140	60	120	80	60	
Sample 11	300	160	120	60	100	
Sample 12	120	60	20	0	120	
Sample 13	140	80	20	60	80	
Sample 14	260	120	20	20	60	
Sample 32	60	0	20	40	0	
Sample 33 450L	80	20	20	0	20	
Sample 35 450L	112	10	0	8	14	
Sample 36 450L	72	6	0	6	4	
Sample 37	12	16	0	0	0	
Sample 38	21	14	21	7	14	
Sample 39	4	8	4	0	8	
Sample 40	8	12	0	0	0	
Sample 39 (re-examined by Mark Gallilee)	20	12	12	16	12	
Sample 40 (re-examined by Mark Gallilee)	32	24	12	4	4	
Control sample 39 (fluid entering vessel)	4	4	8	4	4	
Control sample 40 (fluid entering vessel)	8	4	0	0	4	

Sample Particle count corrected to 100 mls for comparison with the Cleaning Specification (top line numbers)

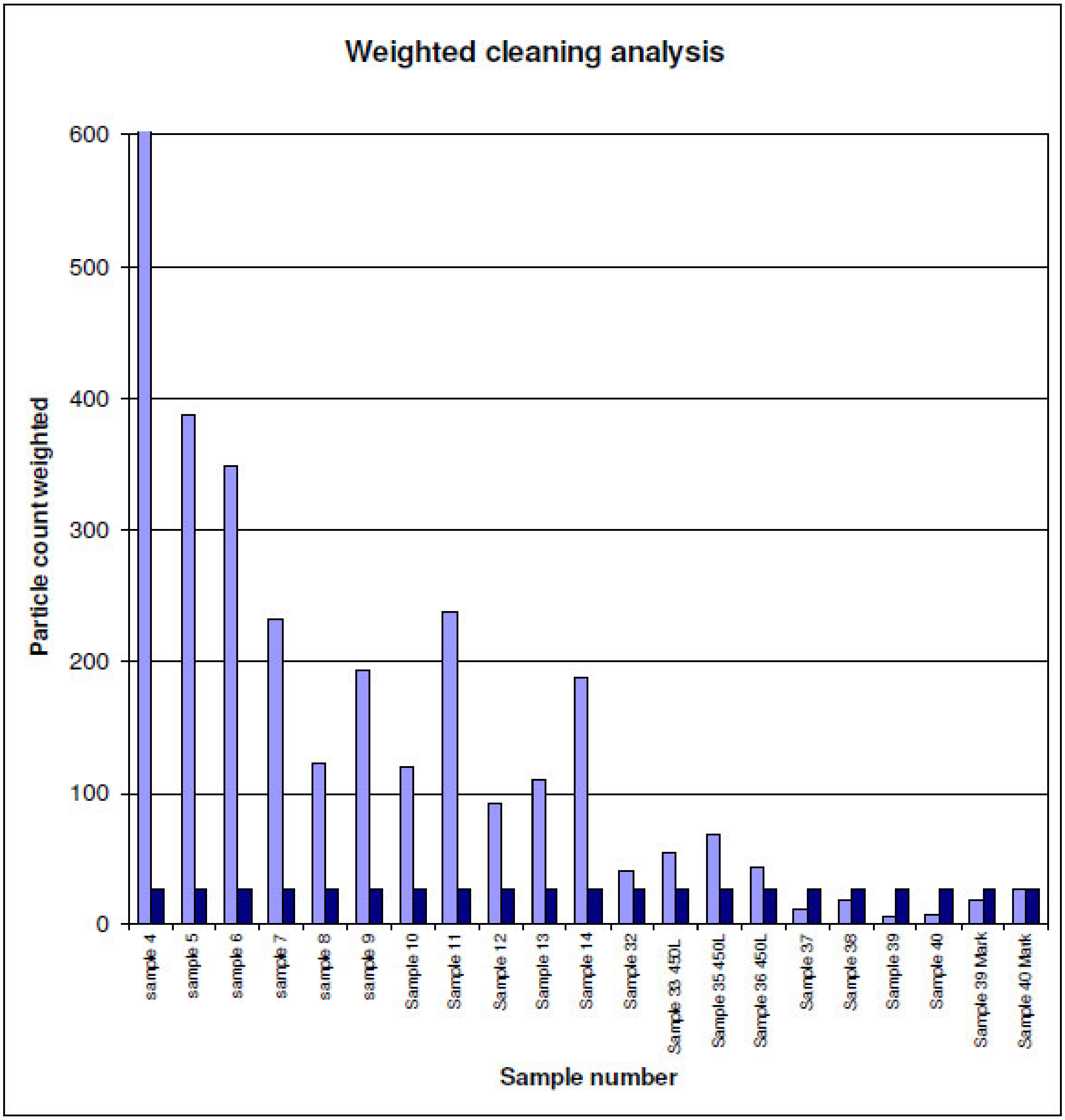


Chart of the 'weighted' particle size count against the IPA cleaning cycle number, showing the improvement in particle count as the cleaning cycles progress.
The dark blue bars show the Cleaning Specification requirement 'weighted' value of 27 units.
The rightmost two values show the re-examination of sample filter papers by Mark Gallilee.

EMAIL Correspondence between project team and the cryogenics experts from NASA Ames Research Center:

-----Original Message-----
From: Louis Salerno [mailto:Louis.J.Salerno@nasa.gov]
Sent: Tuesday, June 12, 2007 8:50 AM
To: Robin Stafford Allen; Tutt, John C. (JSC-EA2)[ESCG]; 'Peter Kittel'; Martin, Trent D. (JSC-EA2); 'Steve Harrison'; Bollweg, Kenneth (JSC-EA2)
Cc: 'Mark Gallilee (SM)'
Subject: RE: Cleaning of Helium Vessel Summary

All,

Thanks to Robin and the entire SM Team for this. I continue to feel that we have achieved the cleanest condition possible using the current methods and that this is acceptable.

Lou

At 06:04 AM 6/12/2007, Robin Stafford Allen wrote:
> To all,
>
>I have updated my report with the details of the 'Control Fluid'
>analysis (ref the email below) and the re-check of the original #39
and
>#40 filter papers conducted by Mark to make sure we have some
consistency in readings.
>Mark's results are slightly higher than when I viewed the filter
>papers, and this could be due to contamination of the papers with the
>passing of time (although they were bagged in the clean room) or some
>other factor, or it could be a genuine slight difference. However
>Mark's analysis does show that using the "weighted" specification
level
>that the last two rinses are still within requirement.
>
>On the conference call on Monday we agreed to continue with the drying
>and vacuum-pumping of the vessel and the flushing of the
>heat-exchangers. This is on-going.
>
>Regards
>
>Robin...
>
>-----Original Message-----
>From: Robin Stafford Allen [mailto:rstaf@scientificmagnetics.co.uk]
>Sent: 08 June 2007 09:36
>To: 'Tutt, John C'; 'Peter Kittel'; 'Martin, Trent D. (JSC-EA2)';
>'Louis Salerno'; 'Steve Harrison'; 'Bollweg, Kenneth (JSC-EA2)'
>Cc: 'Mark Gallilee (SM)'
>Subject: RE: Cleaning of Helium Vessel Summary
>
>Chris,
>
>To answer Peter's and your questions:-
>

>1) Yes I should have labelled the last four washes as 450 L. My
>apologies for this confusion. We have now completed a total of seven
450L washes.
>
>2) I agree that the calculation was very simplistic but it was purely
>to relate the cleanliness to an understandable parameter of the porous
plug.
>
>3) The control fluid samples put through the same procedure produced
>numbers as follows
>
>   <10   <25   <50   <100   >100
>Control 40   2   1   0   0   1
>Control 39   1   1   2   1   1
>
>When multiplied up to normalise to 100 mls and the full squares count
>these become
>
>Control 39   4   4   8   4   4
>Control 40   8   4   0   0   4
>
>And the effective index using the same weighting system
>
>Control 39   5
>Control 40   6
>
>As you can see these numbers are quite similar to the measurements of
>the fluid coming from the vessel and are part of the reason that I
feel
>we are in the diminishing returns of the process. To achieve low
counts
>I am using the cleanest part of our cleanroom for the counting and
have
>fully gowned and gloved before opening samples. I found that if
samples
>of fluid are left in the open for even a few minutes, the number of
>dust particles collected is significant and produce distorted readings
>at these low count levels. The filter papers are even more obviously
>affected by even one or two airborne dust particles.
>
>There is also our old friend Weibull and statistics. When looking at
>small numbers nearing zero there is a probability distribution and
>always some variability. I feel that the few 100 micron bits from wash
>37 fall in this category as there were no significant change in the
>process that I can identify between 36 and 38.
>
>We are setting up to dry the vessel, and I am actually quite pleased
>that we have 'tested' this process by drying it after wash 33 last
>weekend and not seeing a significant increase in particles afterwards.
>We are drawing air from the cleanest area of the clean-room and
ducting
>it into the Porous plug opening through the vessel to enable the IPA
to
>evaporate in the vessel and be carried away out of the burst-disc port.
>It appears to take about 3 shifts to dry out the gross IPA content,
and

>it would be good to do this over the weekend. We will then do another
electrical check.
>
>When we have unanimous agreement that we have achieved the technical
>goal and can stop cleaning the vessel we will move on to the drying.
>
>Any questions, do ask.
>
>Robin...
>
>
>
>-----Original Message-----
>From: Tutt, John C [mailto:John.Tutt@escg.jacobs.com]
>Sent: 07 June 2007 22:34
>To: Peter Kittel; Martin, Trent D. (JSC-EA2); Louis Salerno; Robin
>Allen; Steve Harrison; Bollweg, Kenneth (JSC-EA2)
>Subject: RE: Cleaning of Helium Vessel Summary
>
>Obviously, I'll defer to the experts on whether or not a 1/3 blockage
>of the porous plug would be a mission success issue or not. But I
>think that Robin hit on the key point that we seem to have reached the
>practical limit of what we can do with the current method.
>
>I am curious what happened between sample 37 and sample 38. Whatever
>it was, it seemed to shake loose a large number of particles. That
may
>be worth investigating in case it's something that we might do again
>during normal operations.
>
>Regards,
>Chris
>
>Chris Tutt
>Project Manager
>Engineering and Science Contract Group
>Jacobs Sverdrup
>2224 Bay Area Blvd M/C B2SC
>Houston, TX 77058
>(281) 461-5703
>
>
>-----Original Message-----
>From: Peter Kittel [mailto:pkittel@mail.arc.nasa.gov]
>Sent: Thursday, June 07, 2007 2:35 PM
>To: Martin, Trent D. (JSC-EA2); Louis Salerno; Robin Allen; Steve
>Harrison; Tutt, John C; Bollweg, Kenneth (JSC-EA2)
>Subject: Re: Cleaning of Helium Vessel Summary
>
>Trent,
>
>The figure and table attached to Robin's report does not label the
>last 4 washes as being 450 l. From the text I assume they were.
>Also, I do not see mention of the control - the particle count of IPA
>not used as a wash but otherwise treated the same as the other samples.
>Since the control sample had some particles, The actual particle count
>is probably less than stated in the report.

```
>
>The estimate of the blocked area of the porous plug is probably high.
>
>Particles larger than 10um are likely to loosely accumulate on the
>surface and not interfere with the operation of the porous plug.
>
>Particles smaller than 10 um, especially the very small particles, may
>penetrate into the porous plug.  Alternative calculation might be the
>fraction of the void volume of the porous plug that is blocked.
>
>Overall, I am optimistic that the tank is sufficiently clean.
>
>Peter
>
>
>On Jun 7, 2007, at 10:33 AM, Martin, Trent D. (JSC-EA2) wrote:
>
>>  Please review and comment.
>>
>> -----Original Message-----
>> From: Robin Stafford Allen [mailto:rstaf@scientificmagnetics.co.uk]
>> Sent: Thursday, June 07, 2007 11:38 AM
>> To: 'Stephen Harrison'; Martin, Trent D. (JSC-EA2); Bollweg, Kenneth
>> (JSC-EA2); Tutt, John C. (JSC-EA2)[ESCG]
>> Subject: Cleaning of Helium Vessel Summary
>>
>>
>> Attached is a summary of the situation as it is today, Thursday 7th
>> June. We have completed more cleaning cycles at 450 Litres and I
have
>> added these data points to the tables. I feel they are very
>> encouraging.
>>
>> Please review and do comment
>>
>> Robin...
>>
>>
>> Robin C Stafford Allen
>> Scientific Magnetics,
>> Building E1,
>> Culham Science Centre,
>> Culham,
>> Abingdon,
>> Oxfordshire OX14 3DB
>> Tel: +44 (0)1865 409210.
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>> mailto:rstaf@scientificmagnetics.co.uk
>>
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>> *
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>> 409200. Fax:
>> +44
>> (0)1865 409222. http://www.scientificmagnetics.com/
>> <Cleaning measurements memo.doc>
>
>
>
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Louis J. Salerno
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Group Leader for Cryogenics
NASA Ames Research Center
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Moffett Field, CA 94035-1000
Phone: (650) 604-3189
FAX: (650) 604-0673 Note new FAX number

"Having top people is NASA's good fortune. The privilege of working
with the best is mine." -- Louis J. Salerno

20. AMS-02-A20 – Deviation from documented procedure for Installation of MLI Pins

Description of Event: During installation of MLI pins on the AMS-02 lower USS-02, the process for removing anodization on aluminum surfaces was altered due to the difficulty using documented process. Rather than a slow abrading process a sharp implement was used to "score" the area in a grid-like pattern.

Corrective Action: This revised process is based on the process used on the EuTEF payload, however as this was a deviation from AMS-02 documentation, it was required by the AMS-02 Safety Engineer that each pin be validated to be properly secured with this process (20 pins) to qualify this process on the prepared AMS-02 anodized surface.

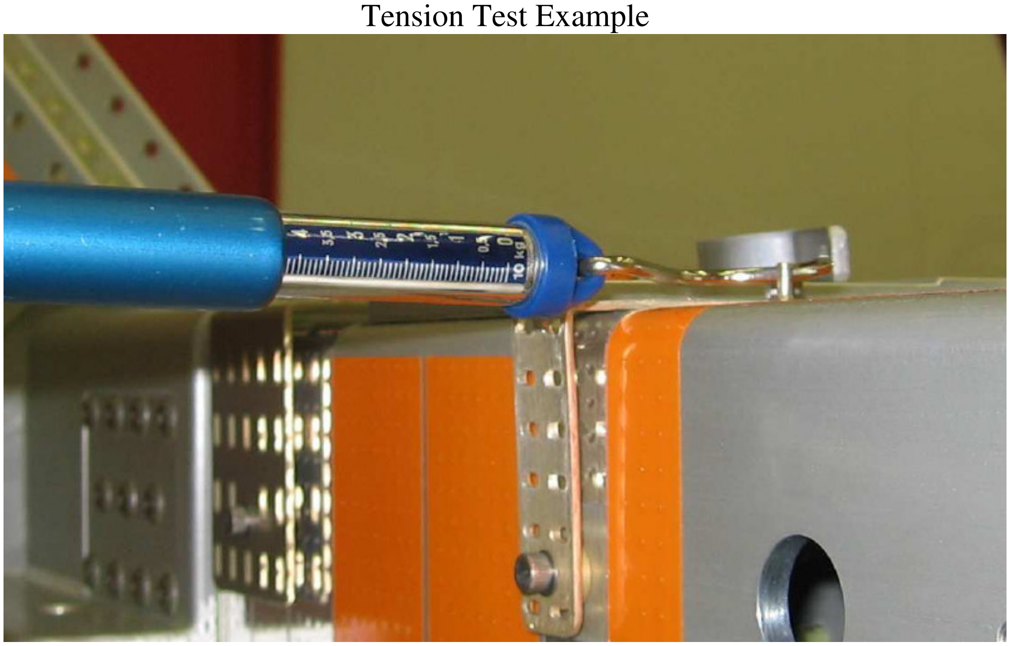
Calculated load on a pin from the installed MLI blanket was established to be no more than 2 kg per pin with a 2.0 factor of safety applied. Testing loads for tensile and shear testing was established from this number to be 4 kg of load to assure that the pins are well secured. Previous qualifications for these pins adhered to an alodined surfaces were shown good to a 10 kg load, but this greatly exceeds the need of the AMS-02 application so testing to this level again was no deemed necessary.

Safety Impact: Potentially the adhesion of the MLI pins would be inadequate to secure the MLI to the AMS-02. With testing, no issue.

Status: Closed. Wednesday November 28, 2007 the pull test on all twenty installed pins were made to a minimum loading of 4 kg in tension (along the axis of the pin) and shear (a lateral force applied to the pin above the adhesion plane). All installed pins passed this test and were deemed adequately installed. This test was considered evidence that any future installation of pins that may support MLI loading per pin of 2kg or less based on a 10g acceleration condition would be enveloped and acceptable using this installation technique.

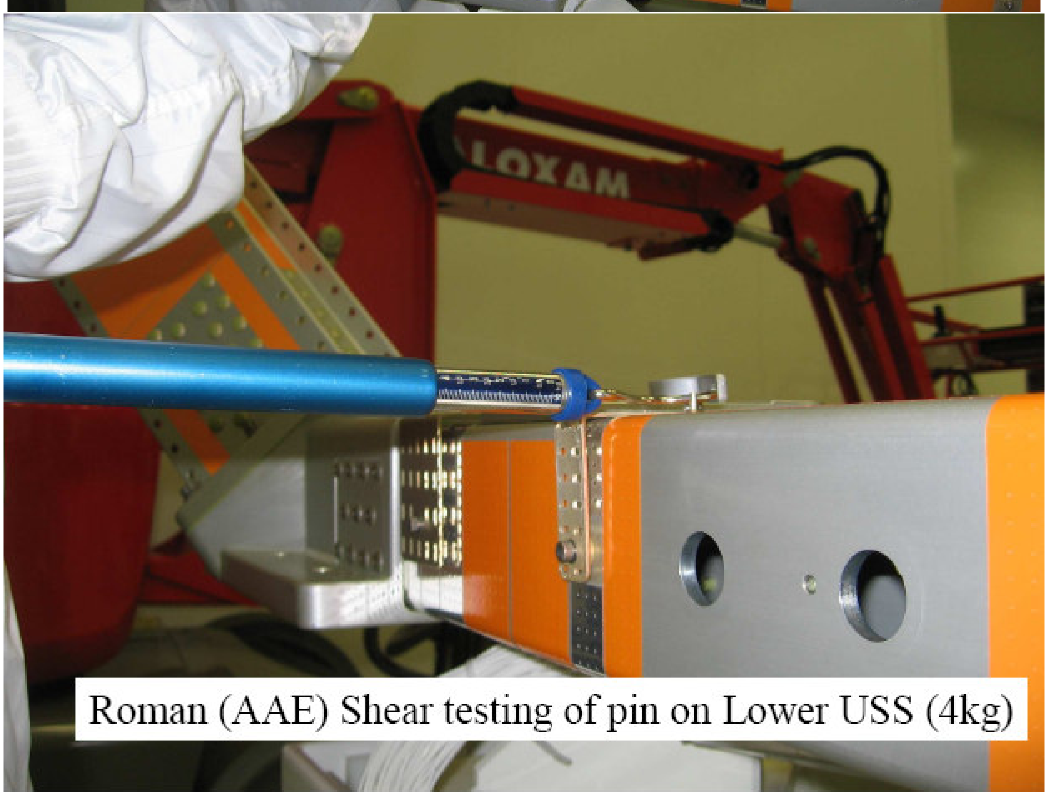
SUPPORTING DOCUMENTATION: (follows)

Tension Test Example



Shear Testing Example

Pull testing pin. All 20 pins successfully passed at 4kg.



Roman (AAE) Shear testing of pin on Lower USS (4kg)